Verifying the Agreed Framework:

Chapters 1—8

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Background Materials for the 2nd Workshop of the Joint CISAC–CGSR Project
To Evaluate Security and Safeguards of the DPRK's Nuclear Reactors
Under the Agreed Framework of 1994

Contents

CHAPTER 1
A Brief History of the DPRK's Nuclear Weapons-Related Effort

This chapter is not a complete history but only highlights those aspects of the history and of the agreements entered into by the Democratic People's Republic of Korea (DPRK) that bear on the safeguards and verification of nuclear facilities and activities. We note and summarize agreements relevant to safeguarding the Korean Energy Development Organization (KEDO) reactors and verifying the frozen or dismantled status of nuclear weapons-related facilities.

1.1 Early History

The Soviet Union began training North Koreans on nuclear matters in the early 1950s. In 1965, the Soviets provided a small, 2-MW(th), light-water moderated, research reactor that burned highly enriched uranium: the IRT-2000 research reactor subsequently upgraded to 4 MW. Then, to reduce its reliance on outside assistance, the DPRK developed the production of both uranium and graphite, began experimenting with plutonium separation, and built a graphite-moderated reactor that burned natural (unenriched) uranium. It was similar in design to the reactors, for example, used by Great Britain to make the plutonium best suited for weapons. It was a 5-MW(e), 20-MW(th)[1] reactor used to irradiate fuel rods from which the DPRK later extracted plutonium. It can probably produce enough plutonium for approximately one bomb per year.[2]

This reactor is located, along with most of the other known nuclear facilities, at Yongbyon in central North Korea (**Fig. 1-1**). Also at Yongbyon are—

- A radio-chemical laboratory for plutonium separation.
- A 50-MW(e), partially built gas-graphite reactor. Its construction has halted, and it has never been operated.
- A small highly enriched uranium (HEU) research reactor that has been decommissioned.
- Buildings, tunnels, and other facilities that have not been declared by the DPRK but that may have been used to store undeclared spent fuel for a plutonium recovery program.

The entire set of facilities at Yongbyon is analyzed in detail in Chapter 6.

The DPRK also has an partially built, 200-MW(e) gas-graphite reactor located at Taechon, and a sub-critical nuclear facility at a university in Pyongyang.[3] Construction on the 200-MW(e) reactor has also been halted.

In 1985, the Soviet Union persuaded the DPRK to join the Non-Proliferation Treaty (NPT) by promising two light-water reactors (LWRs) that were better for producing electric power than graphite reactors but not as good for producing weapons-grade plutonium. Later, the DPRK said it was unable to meet its commitment to pay for even the site-survey conducted by the Soviet Union at a new location in the area now proposed for the new LWRs (see Fig. 1-1). At the end of 1991, after the Soviet Union dissolved into its former republics, Russia withdrew the Soviet promise to provide LWRs to the DPRK.

Figure 1-1. General map of North and South Korea.

1.2 Attempts To Restrain the DPRK From Making Nuclear Weapons

Though a party to the NPT from 1985, for seven years, the DPRK did not accept the comprehensive IAEA safeguards agreement covering all its nuclear activities required by the NPT. Indeed, by 1990, according to one statement, the KGB reported to Soviet officials that it had information that "development of the first atomic device has been completed at the DPRK Center for Nuclear Research."[4] The accuracy of this report has been disputed, but a Russian expert believes it to be authoritative.[5]

In 1991, the Bush administration developed a program to restrain the DPRK from making nuclear weapons. The program relied on South Korean and Soviet efforts as well as those of the U.S. Following the 1991 Bush–Gorbachev announcements of reciprocal withdrawals of most American and Soviet tactical weapons from other countries.[6] President Bush withdrew all U.S. tactical nuclear weapons from South Korea. South Korea then announced a plan for a nuclear-weapon-free Korean peninsula and engaged the North in negotiations that produced a general declaration to this end at the beginning of 1992. This Joint Declaration on North-South Denuclearization not only called for a nuclear-weapon-free peninsula but also prohibited both the North and the South from possessing facilities for enriching uranium or for separating plutonium from spent reactor fuel. Moreover, it provided for reciprocal inspections—of the DPRK by the ROK and vice versa.[7]

Despite lengthy negotiations, the two countries could not agree on the sites in each country that would be inspected by the other. Later in 1992, however, the DPRK accepted the NPT-required safeguards agreement for inspection of its nuclear facilities by the IAEA (INFCIRC 153 safeguards). Before doing so, the DPRK provided the IAEA with a report intended to declare all its nuclear material and facilities for IAEA inspection. When the IAEA's Director General Hans Blix made a visit to these facilities in 1992, he reported among other things that DPRK had a continuing interest in securing LWRs. At that time, however, South Korea rejected the idea of helping the DPRK acquire them.[8]

Before the end of 1992, information from IAEA inspectors and U.S. satellite photographs suggested that the DPRK had probably separated more plutonium from its small graphite reactor's irradiated fuel than the DPRK had reported to the IAEA.[9] When the IAEA requested that special inspections take place at two undeclared sites (in the Yongbyon area), which satellite photographs suggested might be places where the DPRK had hidden the products of unreported plutonium separation, the DPRK resisted strenuously.

After the IAEA Board of Governors insisted upon these special inspections, the DPRK announced that it was withdrawing from the NPT. It gave the required 90-day notice of withdrawal. In the discussions that followed, China opposed going to the U.N. Security Council for an order imposing economic sanctions on DPRK if it withdrew from the NPT. As a result, the IAEA Board of Governors simply reported to the Council what had happened. The Council then called upon the DPRK to permit the IAEA inspections but did not order sanctions if DPRK refused, probably because of the likelihood of a Chinese veto.[10]

China urged negotiations with the DPRK. In consultation with South Korea and Japan, the U.S. renewed such negotiations. On the last day of the 90-day notice period for withdrawal from the NPT, June 11, 1993, DPRK announced that it would remain a party to that treaty, at least for the time being. In a joint statement with the U.S., the DPRK said it had "decided unilaterally to suspend as long as necessary the effectuation of its withdrawal from" the NPT. Both governments "expressed support for the North-South Joint Declaration of the Denuclearization of the Korean Peninsula in the interest of nuclear non-proliferation goals."[11] Both sides agreed to general principles about the application of IAEA safeguards and the need for a "fundamental solution of the nuclear issue on the Korean peninsula." But there was no agreement by the U.S. to provide LWRs to the DPRK and no agreement by the DPRK to freeze the operation of its small graphite reactor or the construction of its two bigger graphite reactors.[12]

Further DPRK-U.S. negotiations produced an agreement in July of 1993 on the following joint statement:

> "Both sides recognize the desirability of the DPRK's intention to replace its graphite-moderated reactors and associated nuclear facilities with light-water moderated reactors (LWRs). As part of the final resolution of the nuclear issue, and on the premise that a solution related to the provision of LWRs is achievable, the USA is prepared to support the introduction of LWRs and to explore with the DPRK ways in which the LWRs could be obtained."[13]

Both sides also agreed to the "full application" of IAEA safeguards to the DPRK nuclear facilities. The DPRK promised to begin consultations with the IAEA on safeguards as soon as possible. Both reaffirmed the importance of implementing the North-South Joint Declaration on Denuclearization, and the DPRK said it was prepared to begin North-South talks on nuclear and other issues. Finally, the U.S. and the DPRK agreed to meet soon to resolve remaining questions including those "relating to the introduction of LWRs."[14]

Meeting again in August of 1993, the DPRK agreed "to replace its graphite-moderated reactors and related facilities with light-water reactor (LWR) power plants," and the U.S. agreed "to make arrangements for provision of the LWRs of approximately 2000 MW(e)" to the DPRK. The U.S. also agreed to make interim energy arrangements so long as the graphite-moderated reactors were not operated. DPRK agreed to "freeze construction" of the two such reactors still under construction, to "forego reprocessing" of spent fuel and to "seal" the radiochemical laboratory where it said reprocessing had taken place. It also promised to remain a party to the NPT and to allow IAEA inspections. In addition, it declared its continuing willingness to implement the North-South Joint Declaration on Denuclearization.[15]

But DPRK disagreement continued with the IAEA over the scope of IAEA inspections, with the ROK and U.S. over whether the annual Team Spirit ROK-U.S. military exercise would be conducted in South Korea that year, and with the ROK over inspections pursuant to the North-South Joint Declaration on Denuclearization. The DPRK shut down its small graphite reactor, which by then may have contained enough unseparated plutonium for at least one bomb. It soon began unloading the fuel rods from the reactor without waiting for IAEA inspectors to test samples of material from them as they were taken out. Such tests could determine which fuel rods had been in the reactor for a long time and which had not, and thereby improve the estimate of how much plutonium had been made within the fuel rods. This DPRK move prompted fear that the DPRK intended to acquire the plutonium for weapons.

Efforts to agree on a U.N. Security Council sanctions resolution failed to gain China's assent. At the same time, U.S. satellite photographs showed the North Korean military forces moving to a war footing. The Pentagon estimated that a war would result in 300,000 to 500,000 military casualties in the first 90 days. No estimates were given for civilian deaths. Both the ROK and Japan opposed going to war with the DPRK.[16]

Then, in a June 1994 visit to DPRK sanctioned by President Clinton, former President Jimmy Carter met with DPRK leader Kim Il Sung and reported to the press afterwards that the crisis was over. He said that DPRK had agreed not to reprocess the spent fuel from the small graphite reactor that had been shut down, to accept IAEA inspection of its reactors and other facilities declared by it to the IAEA, and to freeze its existing nuclear program. In return, the DPRK expected assistance in securing LWRs and an end to U.S. efforts to impose sanctions if IAEA inspectors were denied access to other locations. Thereupon, the ROK announced that it was prepared to provide technology and major financing to the DPRK for two LWRs.[17] It may be noted that this is essentially the same agreement as the one from the previous year, but the DPRK had now prevented the IAEA from making possibly key measurements on its spent fuel, and had delayed the U.S. from imposing sanctions if the DPRK prevented the IAEA from inspecting suspect facilities.

1.3 Agreed Framework of October 1994

When U.S. and DPRK negotiators met again, they produced the AF of October 1994 that gave more detail to the basic agreement announced in the August 1993 joint statement and in President Carter's press conference. The terms of the AF and the subsequent Supply Agreement that implements much of it are as follows:

1.The DPRK and the U.S. "will cooperate to replace the DPRK's graphite-moderated reactors and related facilities with light-water reactor (LWR) power plants." Operation of the small graphite reactor was to be "frozen" and subject to continuing inspection by the IAEA. Construction of two larger unfinished graphite reactors was also to be frozen. Later, all three are to be dismantled. Spent fuel from the small reactor had been removed by DPRK as indicated above. It has since been canned and remains stored in a cooling pond near the reactor. Pursuant to future U.S.-DPRK negotiations, the fuel will be disposed of "in a safe manner that does not involve reprocessing in the DPRK."[18] There was no requirement that DPRK's small Yongbyon research reactor or its sub-critical research facility in Pyongyang be dismantled.

2. The U.S. would make arrangements for provision of the LWRs to the DPRK through "an international consortium" which the U.S. would form and for which it would be the principal point of contact. This consortium, which became known as KEDO, would enter into a "Supply Contract" for the LWRs with the DPRK.[19] At the end of 1995, the DPRK and KEDO signed the Supply Contract for the LWRs. In addition to the U.S., KEDO includes as members and contributors the Republic of Korea and Japan as well as Australia, New Zealand, and the European Union.

3. In the AF, the DPRK promised that it would "freeze" not only the three graphite reactors but also the related facilities, which it had declared to the IAEA. In the meantime, the U.S. and KEDO agreed to make arrangements for periodic delivery of oil to the DPRK to offset the energy foregone due to the freeze on the graphite reactors.[20]

4. DPRK agreed to remain a party to the NPT. It also agreed to "allow implementation of its safeguards agreement under the Treaty [NPT]." However, the U.S. promised the DPRK that the IAEA would not be permitted at first to verify the accuracy of DPRK's initial report on all its nuclear material. This verification could be carried out by, e.g., inspecting the two undeclared and disputed sites where products of earlier separations are believed by the IAEA and U.S. to be hidden. Inspection for this purpose would come later.

> "When a significant portion of the LWR project is completed, but before delivery of key nuclear components, the DPRK will come into full compliance with its safeguards agreement with the IAEA (INFCIRC 403), including taking all steps that may be deemed necessary by the IAEA, following consultations with the Agency with regard to verifying the accuracy and completeness of the DPRK's initial report on all nuclear material in the DPRK."

Thus, before delivery of "key nuclear components," the DPRK must permit IAEA inspection of the two sites where the U.S. and the IAEA believe it has hidden the products of earlier operation of its small graphite reactor. There is evidence, discussed in Chapter 6, that measurements on these products would show that the DPRK removed from the reactor more irradiated fuel than it reported to the IAEA—presumably to separate out the plutonium.[21]

5. "Key nuclear components" include items such as nuclear material, reactors, the equipment attached to reactors other than the turbine-generators, the equipment that controls the level of power in reactor cores, and any other components "which normally contain or come in direct contact with or control the primary coolant." These include, for example, reactor pressure vessels, as well as reactor control rods, pressure tubes, etc.[22]

6. The Supply Agreement states that "the provision of the LWR project and the performance steps…are mutually conditional."[23] As a result, the KEDO delivery schedule is "integrated" with the DPRK performance schedule in several ways. This integration is to be accomplished as follows:

First, DPRK acceptance of IAEA inspections at the disputed and undeclared sites is not required until "a significant portion of the LWR project is completed but before delivery of key nuclear components." This language brought objections from the IAEA because it postpones the "full-scope" inspections necessary to determine whether the DPRK has separated more plutonium than it reported—as is suspected. Major construction of reactor buildings at Kumho, the proposed LWR site, and delivery of non-nuclear components including turbine generators—a "significant portion" of the LWR project—will likely have taken place first.[24] On the other hand, DPRK is not entitled to any key nuclear components if it does not permit these IAEA inspections. Some, including the IAEA Deputy Director for Safeguards, believe that the agreement will likely break down at this point because the DPRK will resist the inspections necessary to bring it into compliance with its safeguards agreement.[25] Others experts believe that, even if DPRK cooperates with the IAEA to permit these inspections, the whole process will require so much investigative work and materials testing that it will likely take two years or more, thus delaying provision of the nuclear components and completion of the program.[26]

Second, when delivery of the "key nuclear components" for the first LWR begins, the transfer of spent fuel from the small graphite reactor must begin. The transfer is to be completed when this first LWR is completed. Again, if DPRK delays delivery of spent fuel, KEDO can delay delivery of LWR components.[27]

Third, "when the first LWR is completed [at Kumho], the DPRK will begin dismantlement of its frozen graphite-moderated reactors and related facilities, and will complete such dismantlement when the second LWR is completed." Thus, KEDO must complete the first LWR before any of the graphite reactors are dismantled but can schedule deliveries for the second LWR based upon DPRK's performance of its dismantlement obligations. The deliveries of the nuclear components for the second LWR can be staged in parallel with proportional steps by DPRK to dismantle all its graphite reactors.

Thus, the Supply Agreement contemplates reciprocal steps of performance to assure each side that the other is doing its part. An agreement that has not been made public provides more detail. And the Supply Agreement calls for negotiation of still another protocol defining the reciprocal steps further.[28]

7. The model for the LWRs will be "selected by KEDO" but was promised to be "the advanced version of U.S.-origin design and technology currently under production."[29] In fact, the reactors will be manufactured in South Korea using as models two existing ROK

reactors based on a U.S.-origin Combustion Engineering design but constitute a refinement of that design.

8. DPRK must eventually repay KEDO for the LWRs "on a long-term, interest-free basis."[30] KEDO will provide nuclear fuel for the initial loading of the LWRs. The DPRK promises to use the reactors, technology, and nuclear material involved "exclusively for peaceful, non-explosive purposes." In addition, it promises not to reprocess or increase the enrichment level of any nuclear material acquired pursuant to the agreement, and not to transfer any nuclear material, equipment, or technology acquired pursuant to the agreement outside the territory of DPRK except for the spent fuel transfer already described.[31]

9. The AF provided that the DPRK and the U.S. would conclude "an agreement for cooperation in the peaceful uses of nuclear energy" as necessary.[32] Later, the Supply Agreement said "In the event that U.S. firms will be providing any key nuclear components," such an agreement would be negotiated "prior to the delivery of such components."[33] These provisions entail a complication.

Agreements of cooperation on peaceful uses of nuclear energy with other nations are authorized by the U.S. Atomic Energy Act.[34] They must lay over in Congress for 30 days without passage of a joint resolution of opposition. It appears that such a procedure will be necessary in this case, but no agreement of cooperation has yet been submitted to Congress. Under recent legislation, an agreement of cooperation indeed cannot be submitted at this time.

Recent legislation requires that the President, when submitting such an agreement with DPRK, certify that IAEA inspections, such as those required by the AF, establish the accuracy and completeness of the report DPRK made to the IAEA when inspections began in 1992. For example, the inspections must establish that there has been no clandestine production of plutonium.[35] Thus, IAEA "full-scope" inspections that may well take two to four years must precede congressional action on an agreement of cooperation.

The AF and Supply Agreement are being implemented by KEDO and the DPRK with considerable success so far, though at a slower rate than the AF contemplated. The site survey for the Kumho site has been completed and major construction to make roads and build buildings for the LWRs and the personnel who will operate them has taken place. KEDO has awarded a "turn-key contract" for manufacture of the LWRs to KEPCO, a South Korean company, which in turn has or will award contracts to four other South Korean companies for nuclear components for the LWRs. Delays have resulted because of difficulties on both sides, and completion is now hoped for by 2007 rather than the 2003 date specified in the AF. Further delay is likely given the anticipated problems described.

Chapter 1 Notes

1. While the DPRK usually designates its reactors by their electrical rating, that rating is the product of the reactor thermal power and the efficiency of the rest of the plant at converting that power into electricity. From the point of view of assessing a plutonium-making capability, the thermal rating, usually three to four times the electric rating, is more relevant. Typically, every megawatt of *thermal* power will generate about half a gram of plutonium per day (actual numbers vary with the type of fuel, reactor design, etc).

2. D. Albright, and K. O'Neill, eds., *Solving the North Korean Nuclear Puzzle* (Institute for Science and International Security, 2000), Chapter 1. M.J. Mazaar, *North Korea and the*

Bomb (London: MacMillan 1995), pp. 25, 29, 36. V.I. Denisov, “Nuclear Institutions and Organizations in North Korea,” in J.C. Moltz and A.Y. Mansourov, eds., *The North Korean Nuclear Program* (New York: Routledge, 2000), pp. 21-26. A. Zhebin, “A Political History of Soviet-North Korean Nuclear Cooperation,” in Moltz and Mansourov, pp. 27-34.

3. D.Albright, F. Berkhout and W. Walker, *Plutonium and Highly Enriched Uranium 1996: World Inventories, Capabilities, and Policies* (New York: Oxford University Press, 1997), pp. 282-284. R.W. Jones and M.G. McDonough, *Tracking Nuclear Proliferation* (Washington, D.C.: Carnegie Endowment, 1998), pp. 158-59.

4. Mazaar, p. 56-57.

5. A. Zhebin in Moltz and Mansourov, p. 35.

6. G. Bunn, *Arms Control by Committee* (Stanford, CA: Stanford University Press, 1992), pp. 251-52.

7. Reiss, p. 239.

8. Mazaar, pp. 84, 86.

9. Mazaar, pp. 94-95; Reiss, pp. 246-49.

10. Reiss, pp. 250-53.

11. Joint Statement of the DPRK and the USA, New York, June 11, 1993.

12. Ibid.

13. Agreed Statement between the USA and the DPRK, Geneva, June 11, 1993.

14. Ibid.

15. Agreed Statement between the USA and the DPRK, Geneva, August 12, 1993.

16. Reiss, pp. 259, 265-271.

17. Mazaar, pp. 162-63; Reiss, pp. 271-272; 275; Leon Sigal, *Disarming Strangers* (Princeton: Princeton University Press, 1998), pp. 155-62.

18. Agreed Framework, pars. I, 1; I, 3

19. Agreed Framework, par. I, 1.

20. Agreed Framework, par. I, 2.

21. Agreed Framework, par. IV.

22. The Supply Agreement refers for its definition of “key nuclear components” to the “Trigger List” developed by the Nuclear Suppliers’ Group to implement the export controls required by Art. III, 2 of the NPT. See M.M. El Baradei, E.I. Nwogugu, and J.M Rames, *The International Law of Nuclear Energy* (Dordrecht, Netherlands: Nijoff, 1993), pp. 1,520-33.

23. Art. III, par. 1.

24. Supply Agreement, Art. III and Annex 4

25. Statement of Pierre Goldschmidt to Bill Sailor at the International Nuclear Materials Manangement (INMM) Annual Meeting in July 2000.

26. David Albright, “Inconsistencies in North Korea’s Declaration to the IAEA” and “How Much Plutonium Did North Korea Produce?” Chaps. IV and VI in Albright and Kevin O’Neill, eds., *Solving the North Korean Nuclear Puzzle* (Institute for Science and International Security, forthcoming in November 2000).

27. Supply Agreement, Annex 3.

28. Supply Agreement, Art. III, 3; Reiss, pp. 276-77.

29. Supply Agreement, Art. I.

30. Supply Agreement, Art. II.

31. Supply Agreement, Art. XIII

32. Agreed Framework, Art. I, 1.

33. Supply Agreement, Annex 3, par. 4.

34. Section 123.

35. North Korean Threat Reduction Act of 1999, Sect. 821-23 of P.L. 103-113. See Henry Sokolski, “Implementing the DPRK Nuclear Deal: What U.S. Law Requires,” *Nonproliferation Review* (Fall-Winter, 2000), pp. 146, 148.

CHAPTER 2
Currently Applicable Safeguards and Related Agreements

2.1 The Existing DPRK Safeguards Agreement

The IAEA-DPRK safeguards agreement is a standard agreement based upon the IAEA's 1971 "model safeguards agreement," INFCIRC 153.[1] Among other things, it provides—

1.The DPRK must establish and maintain a system of accounting and control that will enable the IAEA to verify the DPRK's accounting for its nuclear material at Yongbyon, Kumho, or any other location. It must permit the IAEA to make "independent measurements and observations" to assure the "timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear-explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection."[2] This is the basic standard for the IAEA's INFCIRC 153 safeguards agreements.

2. From the design of a proposed reactor, the IAEA will select "key measurement points," called "strategic points," to be used to measure the nature and quantities of nuclear material, and to determine its flow and inventory. These strategic points will determine the "material balance areas" where the DPRK (subject to checks by IAEA inspectors) will measure what comes into the areas, what goes out, and what is there at the time of measurement.[3]

In order that the IAEA staff may designate these points and areas, decide where sensors and cameras should be placed, and, perhaps, even suggest minor changes in design that would help safeguarding, the papers showing the design of the reactor should be submitted to the IAEA well in advance of the reactor's installation.

3. DPRK is required to provide the IAEA with two kinds of accounting reports for each material balance area: "inventory change reports" and "material balance reports."[4] The first are to be sent to the IAEA within 30 days after the end of the month in which the change occurred. The second are to show the balance based upon a physical inventory of nuclear material in the material balance area and are due within 30 days after the inventory has been taken. More details for the LWRs should appear in IAEA-DPRK "subsidiary arrangements" for the LWRs. These arrangements have not yet been negotiated.

4. The IAEA has the right to conduct "routine inspections" to verify the information supplied by DPRK's accounting system. It can examine DPRK's accounting records, make independent measurements, verify the functioning and calibration of measuring instruments and control equipment, apply surveillance and containment measures (e.g., TV monitoring cameras focused on the reactors and seals on the reactors that, when broken, show that the reactor has been opened when the inspectors were not present). It can also use other unspecified methods "which have been demonstrated to be technically feasible."[5]

5. The Safeguards Agreement calls for one routine inspection per year for small facilities and for material balance areas outside all facilities with a content or annual throughput of nuclear material not exceeding five kilograms. For facilities with annual throughput exceeding 5 kilograms, the "number, intensity, duration, timing, and mode of routine inspections…shall be no more intensive than is necessary and sufficient to maintain continuity of knowledge of the flow and inventory of nuclear material…." The Agreement goes on to specify standards for determining the "maximum routine inspection effort" in

such cases.[6] Presumably an IAEA-DPRK negotiation will determine this effort at a later time.

At the time the IAEA-DPRK safeguards agreement went into effect (1992), the AF had not been negotiated and the safeguards contemplated in the safeguards agreement were for the graphite-moderated reactors. The changes required will likely not be made in the Safeguards Agreement itself but in the subsidiary arrangements for the LWRs.

6. Under the Safeguards Agreement, the IAEA also has the right to conduct "special inspections" if, for example, it decides that the routine inspections and the information and explanation provided by DPRK "is not adequate for the Agency to fulfill its responsibilities under this Agreement." As summarized in Chapter 1, the IAEA secretariat tried to institute a special inspection in 1992 to determine if DPRK had separated more plutonium than it had reported. The IAEA may again seek special inspections when the time comes under the AF for the IAEA to inspect sites not declared as nuclear by DPRK to determine whether DPRK's original declaration of its nuclear materials and facilities is accurate and complete.

2.2 New information That the IAEA May Ask of All States Under INFCIRC 153 Safeguards

As we have seen, "when a significant portion of the LWR project is completed but before delivery of key nuclear components," the DPRK must provide information showing where all the nuclear material in its original inventory has gone.[7] Under "Part 1" of the IAEA's "93+2" decisions to strengthen safeguards, DPRK could also be asked by the IAEA to provide certain information about its past dealings with nuclear material. In describing the 93+2 safeguards requirements, the IAEA legal staff concluded, and the Board accepted, that "Part 1" information, though not always requested in the past, was included in INCIRC 153, the model safeguards agreement upon which DPRK's agreement is based.[8] Some of the Part 1 information that could be asked of DPRK for IAEA use in safeguarding the new reactors is as follows:

- Responses to a detailed questionnaire showing DPRK's system of accounting and control for nuclear material including the scope and timing of DPRK's own inspections and related activities relevant to IAEA safeguards.

- Information on past nuclear activities relevant to assessing DPRK's declarations of present nuclear activities, including the completeness and correctness of its initial report on nuclear material. (There is already a major dispute between the DPRK and the IAEA over accounting for the nuclear material in DPRK's initial report. The IAEA suspects that some of the fuel rods were, after radiation in the small graphite reactor, reprocessed to extract plutonium, after which the plutonium and the wastes were hidden from IAEA inspectors.)

- Information on decommissioned nuclear facilities, and on other locations previously containing nuclear material that had hot cells or where activities relating to conversion, reprocessing of fuel fabrication took place. (This may produce IAEA questions on the DPRK radiochemical lab or on a smaller chemical separation facility that the IAEA Director General Blix suspected DPRK once had.)

- Access to existing historical accounting and operating records predating the entry into force of an INFCIRC 153 safeguards agreement. (Given the length of time DPRK operated nuclear facilities before it agreed to its INFCIRC 153 safeguards agreement, this could produce more IAEA questions.)

- Information on other locations containing nuclear material. (This should include the disputed, undeclared sites.)

The provisions of the AF and Supply Agreement summarized in Chapter 1 that deal with these issues are thus reinforced by the IAEA Board's decision that safeguards agreements like the one applying to the DPRK require the DPRK to supply information of this kind. Chapter 4 provides a much more detailed description of the application of safeguards to the reactors to be provided by KEDO to the DPRK. Chapter 5 presents a few scenarios by which the reactors could be misused for diverting material for possible weapon use.

2.3 Additions to INFCIRC 153 Safeguards for States Willing To Agree to a New INCFIRC 540 Safeguards Protocol

The IAEA "93+2" decision deals with subjects beyond the INFCIRC 153 safeguards agreements, subjects requiring negotiation of an amendment or "protocol" to existing agreements. In its 1996 report on 93+2 to a conference of its members, the IAEA described the new information that would be required as part of what it called the "Part 2" amendments to be incorporated in a new Protocol to the standard INFCIRC 153 safeguards agreement.[9] This new protocol is now called INCFIRC 540. These would require, for example, information *not involving* nuclear material including:

- nuclear research activities and future plans for nuclear developments;
- all activities related to the enrichment of uranium, reprocessing of spent fuel or treatment of nuclear waste before the activities involve nuclear material;
- activities in buildings in sites near nuclear facilities;
- acquisition of a long list of equipment and non-nuclear material related to the operation of nuclear facilities;
- information on materials containing uranium or thorium too low in concentration to be "nuclear material" within the IAEA definition.

The Part 2 requirements were also intended to permit more intrusive inspections, for example, of sites not declared by the facility's government. These had been available for inspection in the past only through "special inspections," which produced much controversy between the IAEA and DPRK. If the IAEA interprets the "special inspection" provision as originally intended and as interpreted in its 1993 case involving DPRK, nevertheless, inspections at other than the declared reactor sites should be possible without amending the DPRK's safeguards agreement to include the "Part 2" requirements.

Part 2 also permits "environmental monitoring" at other locations than those declared by the operator. The IAEA has been doing "environmental monitoring" at some routine inspection sites in other countries. Presumably, it will do this at DPRK routine inspection sites (if it has not already), when, under the AF, it is free again to conduct all the inspections permitted by the existing IAEA-DPRK safeguards agreement.

One of the promises of providing Part 2 information is that it will permit closer cooperation between the IAEA, the operators, and the government officials responsible for nuclear activities. This will result in many fewer inspections for countries like Canada or Japan where a tremendous share of the total IAEA inspections costs has gone in the past. In general, adoption of INCFIRC 540 protocol would, it was hoped, produce a major reduction in the number of inspections in countries that accepted the new safeguards. IAEA safeguards experts question, however, whether that is an objective worth pursuing with the DPRK. Some believe that having more inspections in the DPRK pursuant to DPRK's existing safeguards agreement will be more valuable than attempting to apply the INCFIRC 540 protocol to the DPRK.[10]

Safeguards on the Existing ROK LWRs That Are Models for the DPRK LWRs

The DPRK is to receive two pressurized LWRs of 1,000-MW(e) capacity each, based on a U.S. Combustion Engineering Company design that has been refined by South Korean reactor designers. Two reactors of this design are operating in South Korea. They are both subject to INFCIRC 153 safeguards and are good models for the safeguards anticipated for the two DPRK LWRs. Safeguards on large LWRs of 1,000-MW(e) power or more do not vary a great deal from one reactor to another.[11] Thus, the IAEA safeguards on the KEDO reactors in Kumho will likely be very similar to the safeguards on the ROK reactors expected to be the models for the KEDO reactors. Chapter 4 contains a detailed description of the IAEA safeguards applicable to the ROK reactors.

2.4 Major Challenges Ahead to the Implementation of the Agreed Framework

Most of this report is dedicated to the technical means for verifying that the plutonium produced in the new LWRs at Kumho is not diverted to weapons purposes; that the graphite reactors and other nuclear facilities at Yongbyon and Taechon are dismantled as required by the AF; and that the spent fuel now at Yongbyon is not diverted but is delivered to KEDO when the AF and Supply Agreement require it to be. Other major challenges, however, lie ahead that can prevent or delay implementation of the AF.

Financing

South Korea carries the major burden of financing now. The U.S. has paid for most of the heavy fuel oil delivered to DPRK to fuel its electricity supply, but has not paid for much else. Japan has made major contributions to the already large costs of construction. Australia and the European Union have made smaller ones. Completing construction at Kumho and building the reactors in South Korea will be very costly, and disputes continue over how much each of the interested parties should pay.

Nuclear Liability

This applies, for example, to potential liability if one of the LWRs has a major accident during operations, and some people receive high doses of radioactivity. Congress has prohibited the U.S. from agreeing to indemnify a U.S. manufacturer that provides nuclear components for the DPRK reactors. General Electric has indicated that it will not provide such components without indemnification. South Korea wants KEDO, the European Union, Japan, and the U.S. to assume this liability. Negotiations have not yet produced an agreement to share this liability risk. But, looking to the future, this can become a major problem.

U.S.-DPRK "Agreement of Cooperation" and IAEA Inspection of Undeclared Facilities

This problem was discussed in Chapter 1. Negotiating and implementing a U.S. agreement of cooperation with DPRK permitting the export of necessary nuclear components by American manufacturers seems tightly tied to satisfying the IAEA that the DPRK has declared and reported all its nuclear materials and facilities—that DPRK has not, for example, separated more plutonium than it has declared. Even if DPRK cooperates fully in the IAEA special or other inspections, the process of reconstructing what happened to all nuclear materials in DPRK from the time that it joined the NPT to the present is likely to take two to four years. No Congressional review of an agreement of cooperation and no provision of nuclear components to DPRK is possible until this process is completed and the IAEA is satisfied that DPRK's reports on all its nuclear materials and facilities are accurate and complete. By one estimate, the IAEA would have to complete its inspections and make a decision favorable to DPRK within about 30 months if the export licensing of a U.S. nuclear component or components is not to delay completion of the Kumho project under the present time schedule—which has already been delayed several years beyond the original the original 2003 completion date.[12]

If the IAEA takes around 24 months for its inspections and appraisal, the inspections should begin by mid-2001. But, under the AF, the time has not yet come for the IAEA inspections to begin, as Chapter 1 shows. Implementation of pertinent provisions of the AF may well be delayed for years beyond the four it has already been delayed, unless DPRK agrees to earlier inspections. And, of course, if IAEA inspections and appraisal do not produce the required result, implementation of the AF pursuant to its present terms could end. In Chapter 8, after more complete discussions and assessments of verification and safeguards procedures, we return to the question of how various eventualities could affect verification and safeguards and vice versa.

Chapter 2 Notes

1. The DPRK Safeguards Agreement is IAEA INFCIRC 403, May 1992.

2. DPRK Safeguards Agreement, Art. 7.

3. Ibid., Arts. 46, 98 (m) and (s).

4. Ibid., Art. 63 (b).

5. Ibid., Arts. 72, 74.

6. Ibid., Arts. 79, 80.

7. See Chap. 1, par. 3 and DPRK safeguards agreement, Arts. 8, 49, 63-68.

8. See report by the IAEA Director-General to the IAEA General Conference, "Strengthening the Effectiveness and Improving the Efficiency of the Safeguards System," GC(40)/17 (Aug. 23 1996), Annex II, pp. 5-7.

9. Report of the IAEA Director-General to the General Conference, above, Annex II, pp. 7-15.

10. Personal communication in August 2000 from James Larrimore, former IAEA safeguards expert. Rich Hooper, the IAEA official most closely associated with leading the development of the 93 +2 revisions, believes these revisions should be used in DPRK if DPRK's consent to doing so can be obtained. Personal communication in September, 2000.

11. Personal communication from James Larrimore, August 2000.

12. Sokolsky, supra, p. 149.

CHAPTER 3
The KEDO Reactors and Associated Facilities and Activities

3.1 Introduction

This chapter includes a discussion regarding the location of the KEDO reactors in the DPRK as well as the location of other nuclear-power plants along the shores of the East Sea. The discussion is limited to the large-sized, power-producing reactors that KEDO will provide to the DPRK under the terms of the AF. Further items discussed in this chapter are site-work progress to date, proposed shipments of nuclear fuel into and out of the reactor site, transmission of the generated electricity out of the site, and related ROK energy development issues. All these issues bear on our main topic of safeguards and verification and what will be known under various circumstances.

The proposed power reactors to be built at the Kumho site are often referred to interchangeably as the KEDO reactors (for their provider organization), the Korean Standard Nuclear Plant (KSNP) reactors (for their model name), or the Kumho Pressurized-Water reactors (PWRs) for their general design category. We attempt to use these acronyms where they fit best, but we remind the reader that they refer to the same two PWR-type reactors to be built at Kumho under KEDO sponsorship based on the KSNP model. We remind the reader also that PWRs, as well as Boiling-Water Reactors (BWRs) are types of reactors within the general category of Light-Water Reactors (LWRs). A description of the KSNP reactors (the portions relevant to the safeguards program), as well as a discussion of the proposed safeguards measures, as well as possible additions to them, is provided in Chapters 4 and 5. Other chapters address issues related to the smaller graphite-moderated reactors installed or under construction before the AF at Yongbyon and elsewhere.

3.2 The KEDO Site Location

The KEDO reactors will be built on the shores of the East Sea (sometime referred to as the Sea of Japan or the East Korea Sea). We will use the term East Sea to avoid the clash of perceptions as to the proper name for that sea. The KEDO reactors will be located 30 kilometers (19 miles) north of the village of Sinpo, South Hamgyong Province, about midway along the DPRK's East Sea coastline, a distance of slightly more than 160 kilometers (100 miles) from the ROK border to the south, and about 288 kilometers (180 miles) from the Russian border to the northeast. The nearest town to the site is Kumho, and we have chosen to refer to the site as the Kumho site so as to be consistent with other publications that also refer to the Kumho site.[1] The location of the Sinpo village is shown in **Figure 3-1**. The Kumho site is located in a rural area away from the main DPRK population centers around the Pyongyang area to the west and around Congjin close to the Russian border to the north. The climate at the site is dry and cooler than in Pyongyang or Seoul, though the seaside location moderates the winter temperatures.

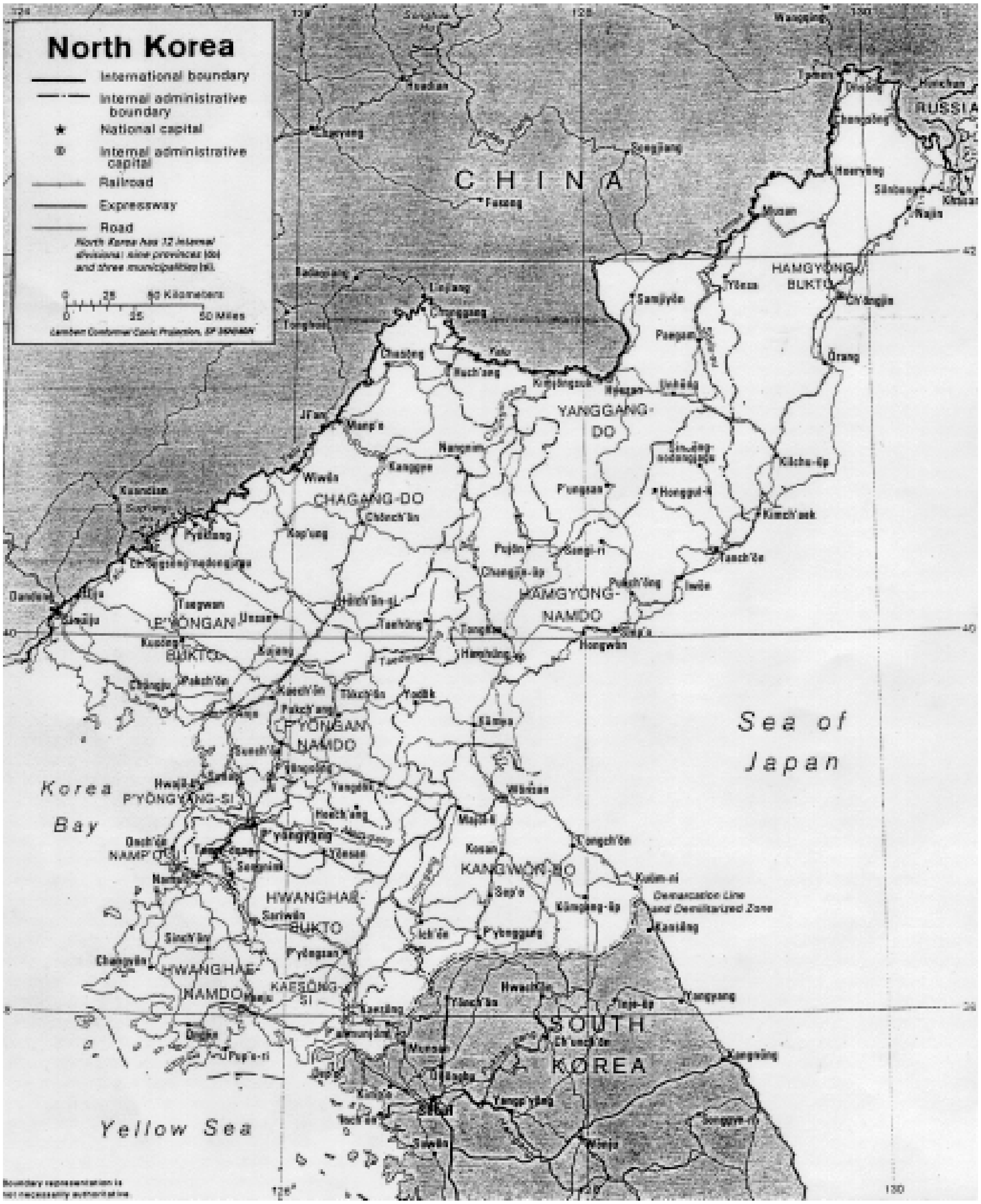

Figure 3-1. General map of the DPRK.

The Kumho site was chosen as it has already been selected in the past for three Russian 640-MW(e) VVER-1000 reactors, and has thus been cleared as a prospective nuclear-power plant site. Russia (then the Soviet Union) had promised those reactors to the DPRK as a part of the international nuclear electrification program of the Comecon Organization. In fact, two similar reactors (though of more updated design) are now being constructed in the People Republic of China (PRC), in Tinwan, Jiangsu Province.[2] Early site work for the Russian reactors project in Kumho began in 1990 and ceased with the collapse of the Soviet Union, and in face of the DPRK's apparent inability to pay the cost of this large project with its own resources.

There were several advantages for choosing the Kumho site as a prospective nuclear site:

- A seaside site that can use seawater for condenser cooling. The seaside location and availability of barge docking facilities at Sinpo and on -site permit barge shipment of heavy equipment items as well as fresh and spent fuel, rather than having to rely on the more dilapidated DPRK road and rail networks.
- Location in a low-density rural area, thus minimizing potential routine or accidental radiation exposure,
- A hard-rock site with adequate bedrock area at grade level, thus allowing the entire reactor building to be constructed above grade as the Russian design required.

On the other hand, the distance from the load centers requires the construction of high-voltage transmission lines to transmit the large amount of electricity generated on site to the ultimate consumers.

3.3 Nuclear Power Development Along the Shores of the East Sea

The KEDO reactors at the Kumho site will join the large number of other nuclear facilities located along the shores of the East Sea. The four littoral states—ROK, DPRK, Russia, and Japan—have turned the East Sea into one of the most heavily ‘nuclearized’ areas of the world.[3] **Figure 3-2** indicates that the ROK and Japan have located several large plant clusters along the shores of the East Sea. The ROK has located three of its four nuclear sites on the eastern part of the peninsula, starting with Kori—the first ROK nuclear-power station of 2,940 MW(e) net capacity—extending to Wolsung, the Korean-Canadian CANDU reactors station of 2,800 MW(e) capacity, and to the Ulchin station with 3,900 MW(e) installed capacity that includes the first of the series of the standardized KSNP plants, two of which are planned for the KEDO site. Two KSNP reactor stations, each one similar in size to the KEDO station, are planned for the Kori and the Ulchin sites. Additionally, a new nuclear site will be opened up in Bong Jil, just north of the Wolsung station. That site could accommodate four KSNP reactors or four advanced CANDU reactors.[4,5]

Should relations between the DPRK-ROK continue improving, and should the ROK’s nuclear program suffer from lack of nuclear sites, as discussed below, then it is possible to assume that additional ROK reactors will be built on DPRK sites, probably starting at the Kumho site, to generate power for transmission to the ROK. This will result eventually in additional nuclear stations located on the DPRK section of the East Sea coastline.

The Russian navy has major nuclear facilities in the Valdivostok and Nakhodka harbors on the shores of the East Sea. A large part of the nuclear-powered surface ships and submarines of Russian Navy’s Pacific Fleet are home-ported at these two harbors. Naval facilities in this area include storage of spent fuel and low-level waste from Pacific Fleet ships and submarines. All these facilities need upgrading to Western radiation-exposure and emissions-control standards. The Russians have long-term plans for the construction of the Primorski Kray nuclear-power station north of Vladivostok, and discussions have been held since 1995 with both Russian and Canadian organizations to that purpose.

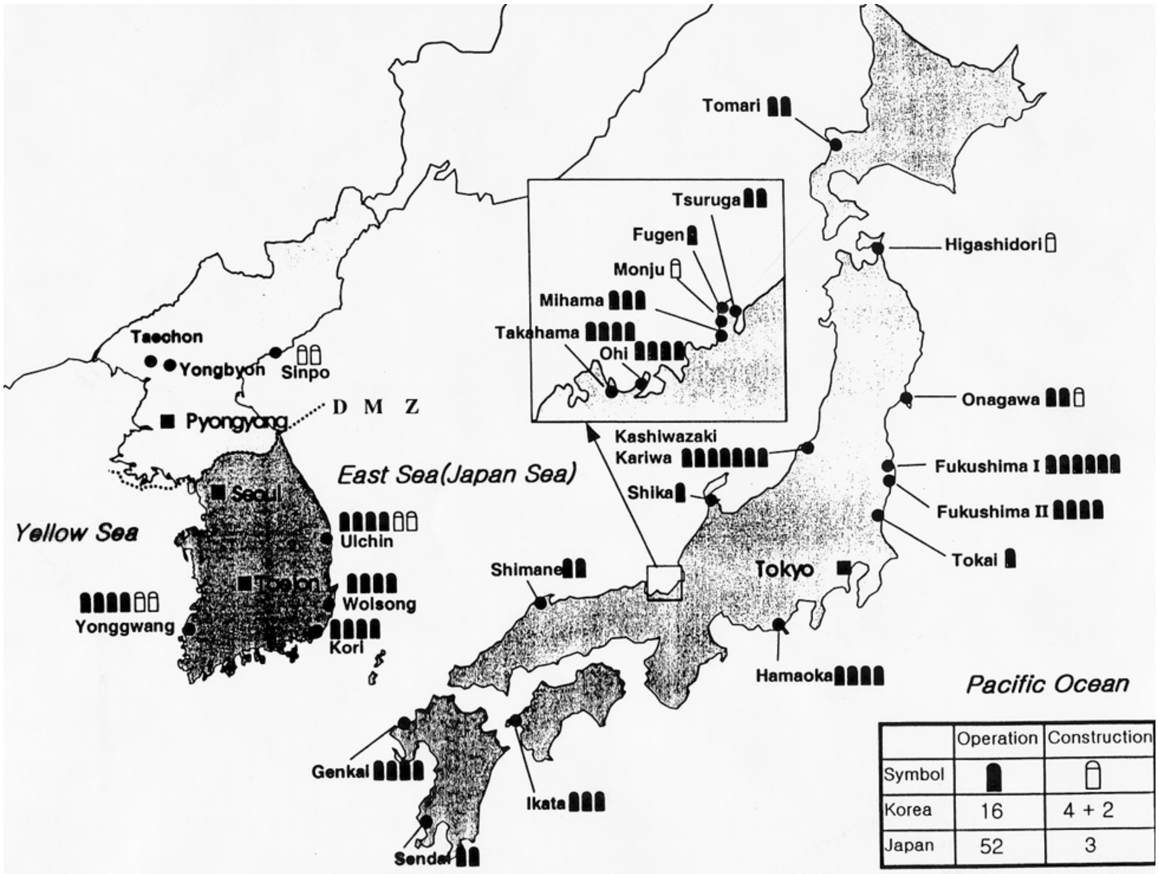

Figure 3-2. Locations of nuclear facilities around the East Sea.

The extensive, peaceful nuclear-power program in Japan has resulted in a large number of nuclear sites located on the shores of the East Sea. Among the more important facilities, we should mention four. The national fuel-cycle center in Rokkasho Mura, located at the northern tip of the main island of Honshu, includes a uranium-enrichment plant, a French-designed fuel-reprocessing plant of 800 tonnes per year capacity now under construction, a large-sized spent-fuel storage pool, and the prospective Higashidori nuclear-power plant site. The Kashiwazaki-Kariva nuclear-power station, with five 1,100-MW(e) BWR-5 reactors and two 1,350-MW(e) Advanced BWRs, is the largest nuclear station in the world with more than 8,000 MW(e) of installed capacity. The Japan Atomic Power Company (JAPCO) has new prototypes station in Tsuruga that includes, among others, the 150-MW(e) plutonium-burning Fugen Advanced Thermal Reactor (ATR) and the 250-MW(e) Monju experimental Liquid Metal Fast Breeder Reactor (LMFBR). And lastly, three PWR stations of the Kansai Electric Power Company are clustered at the Mihama, Takahama, and Ohi sites with a total installed net capacity exceeding 9,200 MW(e).

The profusion of nuclear-power stations and fuel-cycle facilities located on the shores of the East Sea, to which the KEDO reactors will be the latest addition, may well require the littoral states to reach agreements about regulating water effluents and air emissions from these facilities. Such agreements may well have to include provisions for emissions monitoring, effluent control standards and cross boundary pollutant damages, and third-party liability in cases of nuclear accidents. In fact, it may be to the advantage of these states to harmonize and improve their nuclear-insurance regulations to meet current standards, at least at the levels proposed by the IAEA. Implementing such measures will be essential for the well-being of the citizens of all the four states involved, if nuclear-power expansion is to grow at the announced levels and provide the energy benefits it promises.

3.4 Site Work to Date

KEDO initiated preliminary work at the Kumho site office shortly after its inception. Major work at the site was initiated only after the signing of the Preliminary Works Contract (PWC) between KEDO and Korea Electric Power Corporation (KEPCO) in August 1997. The PWC has been incorporated into the main Turn Key Contract (TKC) between KEDO and KEPCO, signed in December 1999, and it is now included in the overall KEPCO scope for the KEDO reactors. The full value of the PWC site-related work scope is estimated at $93 million, out of a total KEPCO work scope under the TKC, estimated at $4,080 million. Information on the work progress to date can be obtained from the KEDO Annual Reports.[6] As part of its activities, KEDO has opened an office in Kumho to interact with the DPRK General Bureau for the LWR Project (GB) on project- and site-related issues. KEDO also cooperates with the DPRK regulatory authority—the State Nuclear safety regulatory Commission (SNSRC) on matters related to DPRK safety evaluation of the KSNP reactors and to the training of nuclear plant operators and maintenance crews.

Site activities to date have concentrated on three areas as seen in **Figure 3-3**, including the construction housing and warehouses area, the reactors site, and the process-water intake site, some 20 kilometers away from the reactors site.[7] KEDO has also interconnected all three sites with a road system considered among the best in the DPRK. The housing area now includes now includes facilities for several hundreds construction workers and visitors. It includes medical, dining, banking, and recreational facilities. Construction and design offices were also built, as well as warehouses for the construction equipment and supply items. KEDO has also established independent supplies of reliable electricity, potable water, communications system, and constructed environmental monitoring facilities.

A future site view[7] of the KEDO reactors plant is shown in **Figure 3-4**. In terms of work to date, KEPCO under the PWC has concentrated on site grading and removal of a large hill from the area where the reactors are to be constructed. The scope of the grading effort is graphically depicted in **Figure 3-5** where the dimensions of the graded area are shown in relation to the size of the future KSNPs.[7] In total, about 4 million cubic meters of rock and soil have been removed down to the bedrock. The exposed bedrock at grade level now forms the ‘platform’ over which the base mats for the two reactor plants will be laid. The excavated rock materials are used to create the breakwater for the docking harbor on site, which will be used to barge-transport heavy equipment items to the construction site.

With the signing of the major TKC, the direct responsibility for the KSNP reactor construction has devolved to KEPCO as the KEDO General Contractor. KEDO itself continues to negotiate with the DPRK and the ROK authorities various other contracts that will govern the construction work and the reactors commissioning and operations phases. A Memorandum of Understanding (MOU) was signed with the DPRK on September 1999, regarding environmental protection and indemnification. An Operators’ Training Protocol was completed on April 2000 and is ready for formal signature. Substantial progress was achieved by July 2000 on a Protocol dealing with Quality Assurance and LWR Equipment Warranties. KEDO has negotiated with the IAEA to conduct a Standard Design Safety Review of the proposed Kumho reactors by mid-2001. KEDO is discussing in parallel with the DPRK the strengthening of its regulatory agency—the SNSRC. As a part of its extensive safety-related discussions with the DPRK, KEDO has transferred to the DPRK copies of the ROK regulatory agencies’ Safety Review Guidelines, the ROK Atomic Energy Act and Enforcement Decrees, and a large number of codes and standards adopted in the ROK nuclear energy program. KEDO has also conducted detailed discussions and seminars with the DPRK SNSRC and GB regarding the application and implementation of those documents.

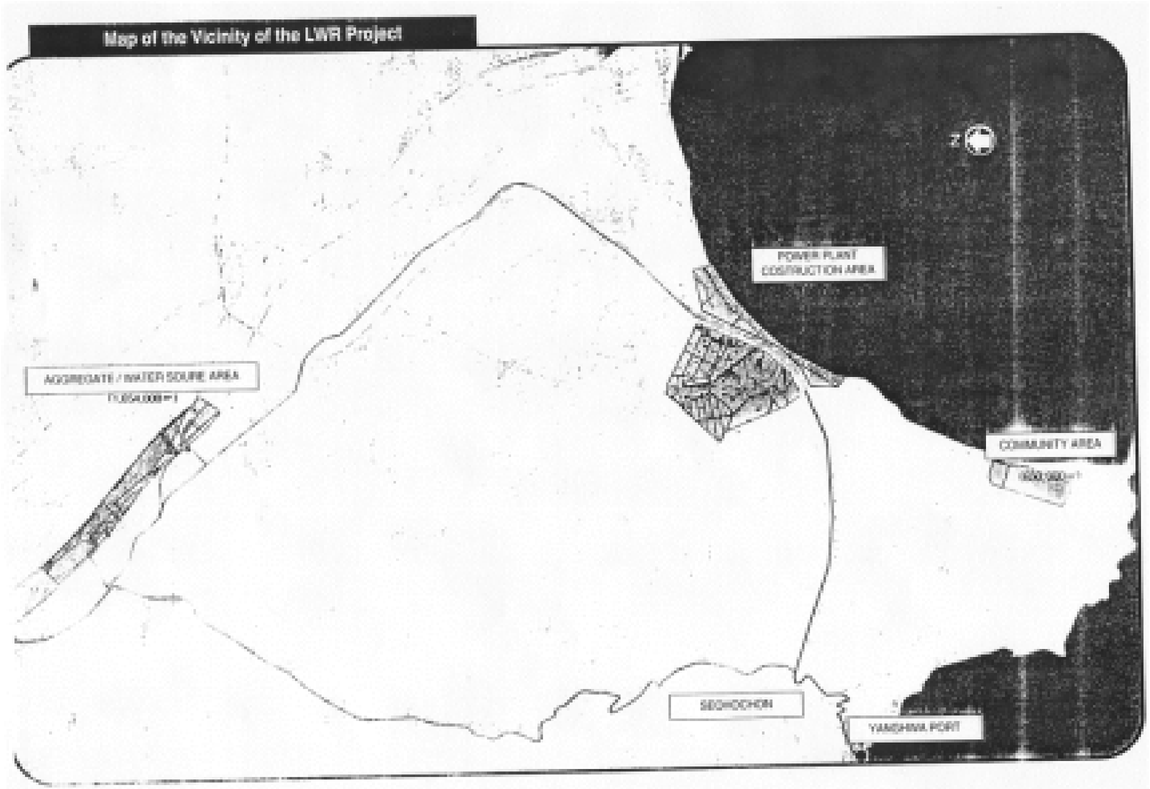

Figure 3-3. Map of the vicinity of the Light-water Reactor (LWR) project.

Figure 3-4. Artist s concept of the future site for the KEDO reactors.

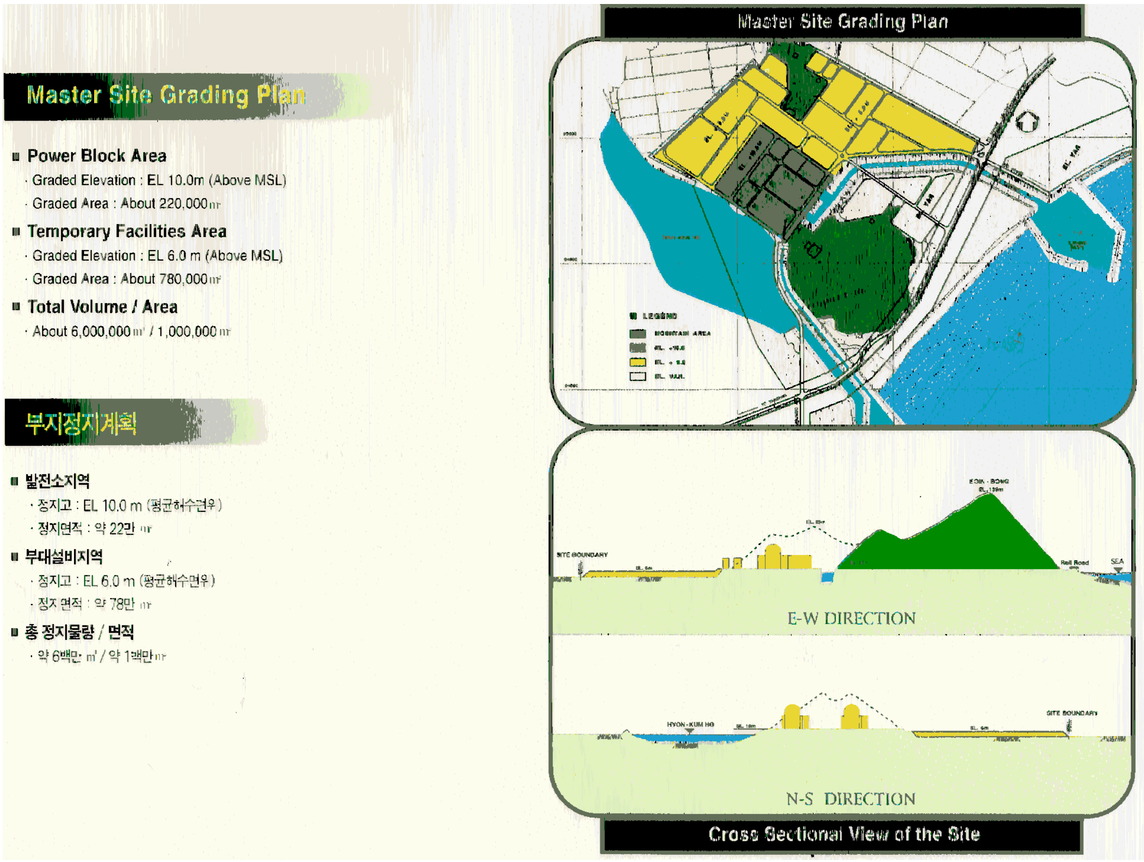

Figure 3-5. Scope of the grading efforts in the construction area.

3.5 Nuclear Fuel Shipments Into and Out of the Site

It is likely that fresh nuclear fuel to the KEDO reactors and spent nuclear fuel discharged from the reactors will be shipped in and out of the Kumho site by barge to the ROK because road and rail links between the DPRK and the ROK have not yet been established. A trial opening of the Seoul-Pyongyang rail line occurred in October 2000; however, commercial rail service between the two countries is speculative. Furthermore, the status of road and rail overpasses, underpasses and junctions that need to be traversed, as well as the general condition of the transportation routes may not allow use by bulky, overweight spent fuel (and even the lighter fresh fuel) transporters. A heavy spent-fuel-cask rail car may weigh about 100 tons. It is not clear that the DPRK rail network could safely carry cars of this weight. Should a transportation accident happen due to the inadequate maintenance of the road or rail links and various junctions along the routes, the accident consequences may be severe, and the fuel insurers may not even allow such transportation.

From a non-proliferation perspective, once spent fuel is moved out of the Kumho site, the shorter the time period as it moves through DPRK territory, the less chance for attempted fuel diversion, or for delaying the spent-fuel transport and using it as a bargaining chip in some future negotiations. From all the perspectives mentioned above, moving the fuel in and out of the Kumho site by barge is the feasible and desirable transportation mode.

As discussed later in Chapter 4, each of the two KSNP reactors on site at Kumho will be refueled every 18 months, as is the practice with all the other KSNP reactors operated by KEPCO. In general, it is KEPCO's intention to, as much as possible, build and operate the KEDO reactors like all other KSNP reactors operated in the ROK. This issue is discussed next.

A typical KSNP reactor requires 60 new assemblies of fresh fuel loaded into the core on every 18 months' refueling outage. In parallel, 60 assemblies of spent fuel are discharged from the reactor and stored in the spent fuel pool, located in the fuel building adjacent to the reactor containment building. Each assembly weighs slightly more than half a ton (1,000 pounds). A fresh fuel load required every 18 months then weighs less than 35 tons. The fresh fuel assemblies are only slightly radioactive and can be handled by hand, with most of the alpha activity of the low-enriched uranium (LEU) being contained in the zirconium oxide-clad material. Thus, the fresh fuel shipment into the Kumho site does not pose any transportation difficulties and can be carried out by two commercial trucks.

It is likely, though not yet established, that the DPRK will purchase its natural uranium requirements in the world markets and will ship them to one of the major uranium enrichment vendors, such as the United States Enrichment Corporation (USEC), for enrichment. The LEU produced by USEC will be converted to uranium oxide in the U.S. and then shipped to the ROK's fuel-fabrication plant, operated by Korea Nuclear Fuel Corporation (KNFC) in Taejon. KNFC fabricates all the fuel assemblies for the ROK nuclear plants in Taejon, and it will likely fabricate the fuel assemblies for the KEDO reactors just as it fabricates fuel assemblies for all other KSNP reactors. From Taejon, the fabricated fuel assemblies will be trucked onto a barge docked in the designated ROK harbor and the barge will carry the nuclear-fuel shipment to the Kumho site barge harbor, whence the fresh fuel will be tracked to the reactor fuel buildings.

Unlike the fresh-fuel-shipment process, which is quite straightforward, the issue of spent fuel shipment is more complicated. Spent fuel discharged from the reactor is highly radioactive. Current industry practices call for keeping the spent-fuel assemblies in storage in the spent fuel pool in the fuel building on site until their residual radioactivity has been sufficiently reduced through the natural decay of the short-lived fission products before shipping the assemblies in a heavily shielded container. Usually, spent fuel is kept in wet storage on site for at least ten years. Most spent fuel pools can be further re-racked and equipped with neutron absorber plates to increase their storage capacity to more than 20 years' worth of discharge, while avoiding potential nuclear criticality accidents. Under these conditions, and assuming the KEDO reactors reach commercial operation in 2008, it may not be necessary to ship spent fuel out of the Kumho site prior to 2020, unless so required by non-proliferation considerations or by special contracting conditions. It is more likely that with proper standardized re-racking measures, the KEDO spent fuel will not have to be moved out of the storage pools in the reactor's fuel buildings prior to 2030.

At this point, KEPCO has not yet developed its long-range, spent-fuel management plan for its KSNP reactors. KEPCO may well decide to keep all old spent KSNP fuel discharge in concrete dry-storage casks at each site, rather than remove the spent fuel to a central storage facility. At this time, no ROK-centralized, away-from-reactor, spent-fuel storage facility has been developed and built by KEPCO. Thus, KEDO may well decide, all other things being equal, to keep the KEDO reactors' old discharged fuel in the spent fuel pools in the reactor buildings and then in dry storage casks on site at Kumho, until KEPCO's spent fuel disposal plans are firmed. Alternately, if the spent fuel is to be removed from the Kumho site as quickly as feasible, a storage facility in the ROK or a third country has to be so designated, and that facility has to be designed, licensed, and built. That process may require 20 years or more due to potential public opposition to storing spent fuel from a different country. Thus, the fate of the KEDO reactors' spent fuel is yet quite uncertain, though adequate time remains before the spent fuel pools on site will run out of storage capacity.

Once a decision is made to remove the spent fuel from the Kumho site, it is necessary to bring a heavily shielded storage cask to the site. Such a cask, depending on the number of spent fuel assemblies it carries, can weigh up to 100 tons and is usually rail-mounted. The cask will have to be barge-shipped into the site and then moved by rail from the barge harbor on site to the fuel building at each reactor. The spent fuel will be loaded into the cask in a special section of the spent fuel pool inside the reactor building (discussed in Chapter 4). The loaded and sealed cask will then be lowered into its rail carriage and moved into the barge, which will carry it to its destination in the ROK or beyond. There the spent fuel will then be removed and the cask be readied for another shipment.

3.6 Electricity Transmission Issues

As important as the fuel shipment into the site is the issue of electricity transmission out of the site. The U.S. Energy Information Administration (EIA) estimates the total electricity generating capacity of the DPRK by January 1998 as 10,000 MW(e),[8] with total generation in 1998 of 32.0 billion KWh. Hydroelectric plants provide 50 percent of the installed capacity and 70 percent of generation nation-wide, and the rest is provided by a mix of coal- and oil-fired thermal power plants. Peter Hayes of the Nautilus Institute[10] provides a similar estimate for total installed capacity—9.75 GWe. According to Hayes, the DPRK energy crisis of 1996 resulted in only 2-3 GWe of installed capacity in operation by the year 2000 due to the lack of commercial fuel, cancellation of subsidized oil supply from Russia, and drought seasons. Total generation by 2000 is estimated at only 15.0 billion KWh. The KEDO reactors will inject a 2,000-MW(e) capacity increment into the DPRK power grid, with each reactor generating about 7.0 billion KWh per year (assuming annual operation at 80 percent capacity). Evidently. the KEDO project will become a major generating center in the DPRK, providing about a third of all DPRK generation from the Kumho site by 2010, when both reactors reach commercial operation. In fact, the total generation from both reactors by 2010 will nearly equal the total commercial electricity generation in the DPRK in 2000.[9] This situation will create several problems, the four most important ones being the disposition of the generated electricity, network stability, reliability of power transmission, and the supply of high-quality power in-house load.

The electricity generation from the KEDO reactors beyond 2010 will likely significantly exceed the total demand of the DPRK, assuming other existing generating plants are brought again into commercial operation once economic recovery is under way. Eventually (though this may be postponed for many years), the DPRK will have to earn hard currency to pay its obligations to return the KEDO participants, principally ROK and Japan, at least a portion of their investments in the Kumho reactors. Both supply-and-demand considerations, as well as hard currency requirements, imply that a large portion of the generated power will have to be dedicated for exports out of the DPRK. The only nearby countries that can take the KEDO reactors output are the ROK, the PRC, or Russia. Of these three, Russia is in most immediate need for power import due to severe energy shortage in the Vladivostok and the Primorsk regions. Russia may, however, lack the hard currency required for such energy export. Furthermore, the transmission links from the Kumho site to the Russian border are the longest, thus requiring more investments in rebuilding and upgrading the DPRK transmission network. Nearer-term interconnections may include ROK-DPRK, PRC-DPRK or ROK-DPRK-PRC links.

Shipping the KEDO reactors' power to market via the ROK-DPRK transmission link has been costed and is the most technically feasible and potentially near-term option. Even now there exist limited diurnal and seasonal electricity interchanges between the ROK and the DPRK. Transmitting the KEDO reactors output to the ROK would expand the existing ad hoc arrangements several-fold. Given the high-growth rate of electric demand in the ROK—now that the country's economy is emerging from the 1998 financial crisis—having access to the KEDO reactors will allow deferment of a new power plant project by several years, which will be beneficial considering the paucity of new plant sites available in the ROK. The DPRK will benefit from the energy payments received. KEPCO has by now evaluated the feasibility and the cost of creating such transmission interlinks and will most likely be ready to implement such a project once international financing is available and the political approvals are obtained. The main problem with this concept is the political dimension. Connecting the ROK and the DPRK transmission networks will require integrated operation of both networks, most likely under the technical control of the more advanced ROK side. This dependency on uninterruptible transmission flows could lead to a loss of political freedom of action unacceptable to the DPRK leadership. Thus, technical and political feasibility considerations seem to operate in different directions as related to the large-scale ROK-DPRK transmission link.

Another option would be to connect the KEDO reactors to the PRC's Northeast Power Network. Such an arrangement would bring additional power supply to the fast-expanding PRC energy market and would defer the need to construct new, mainly coal-fired plants in the Northeastern Provinces by several years. Deferring additional coal-fired capacity would reduce regional air pollution and may qualify the PRC for carbon-emissions reduction credits under the Clean Development Mechanism (CDM) of the Kyoto Protocol. The major problem with the DPRK-PRC transmission link would be the longer transmission lines required from the Kumho site to the Chinese border—500 kilometers as compared with the transmission lines from the site to the ROK—about 200 kilometers.[9] A more stable, long-term solution might be a three-party transmission interlink connecting the ROK network to the DPRK network at the Kumho site and then further connecting to the PRC's Northeast Power Network. Such an arrangement could benefit all three parties, but connecting the currently decrepit DPRK transmission network to another country, let alone integrate it to two different networks, would be difficult. Before discussing regional transmission schemes, it is necessary to consider some of the practical concerns related to integrating the KEDO reactors into the DPRK transmission network. These concerns relate to the stability of the existing DPRK transmission grid, the hurdles of interconnection to other grids, and the interaction of the grid with the KEDO reactors.

Network stability problems occur when a large-capacity generation plant or load center appears in the transmission network, thus creating a large electricity source or sink in the network, which in turn results in high electric currents in the grid that may exceed its carrying capacity. As a general rule, a single generation node should not exceed 7 to 10 percent of the total system generation for stability and reliability. Because the KEDO generating plant will exceed the limits of this network stability-reliability rule, it will be necessary to transmit power out of the site in several high-voltage transmission lines that will overlay the current lower voltage transmission system, and interconnect to it at several different nodes through step-down transformers. Furthermore, because the DPRK's total generating capacity once the KEDO reactors are in operation will exceed demand for years to come, it may be necessary to back down (or, in fact, defer restarting) some of the existing fossil thermal plants to make room for the newer, more efficient, and more cost-effective nuclear plants. Nuclear plants have to operate at base load, and cannot cycle well to meet the fluctuating load. Thus, the DPRK's electric system planners may choose to utilize their hydroelectric plants at full capacity during the good hydro months, and use their nuclear plants as base load units. However, some of the thermal plants cannot shut down due to local network stability problems in sections of the transmission network. The DPRK's system planners will have an intricate job of balancing the transmission network and assuring its stability after introducing the large-sized KEDO reactors into their national grid. While these issues can be resolved using advanced electrical engineering equipment and software tools, these are not the problems that the DPRK planners have encountered to date, and they may face many new challenges, including some possible reactor safety issues.

As noted, the high-voltage (345 kV or 500 kV) transmission lines out of the Kumho site will form a separate network that will overlay the existing mainly 220-kV transmission grid and interconnect with it near load centers. The DPRK's electric planners favor the 500-kV lines, while the backbone of the much larger ROK transmission grid is the 345-kV high-voltage lines. Assuming each line from the site will carry the electrical output of one KSNP reactor, then at least two high-voltage lines have to be constructed. From a reliability perspective, three lines is the preferred option to take care of potential outages in either of the two other high-voltage lines or their step-up and step-down transformers. The three lines option is more expensive than the two lines option, though it avoids the need for using other, less optimal reliability measures.

The DPRK does not have the resources to finance construction of these high-voltage lines. Financing has to be provided by international lending institutions or from contributions by third parties. Extending the high-voltage transmission lines to the ROK or PRC grids, as discussed above, could bring in the hard currency required to pay for the transmission lines, as well to pay back the investment costs in the reactors, which the DPRK is obligated to do.

Another problem affecting the integration of the KEDO reactors into the DPRK grid as well as any interconnection with the ROK or the PRC grids is that the DPRK network operates at an effective frequency of 50 Hz, whereas both the ROK and PRC networks operate at 60 Hz. The KEDO reactors, being similar to other ROK KSNP reactors, are designed to operate at 60 Hz. In addition, both voltage and frequency on the DPRK grid fluctuate around the nominal values at wider amplitudes than are acceptable from stability considerations in the more modernized and mature ROK and PRC grids. At the interlink points, it may be required to install AC-DC-AC converters to eliminate the voltage and frequency fluctuations of the DPRK grid. Similar measures may be needed when providing in-house power from the DPRK grid to the KEDO reactors. While these problems can be resolved by standard electric transmission equipment, these will increase the cost of the entire AF project. These difficulties could be relevant to the question whether "reactor completion" means the point in time when the reactors can generate, or whether the completion date is the time when the plant's electric output reaches the ultimate consumers.

The cost and completion date issues become particularly pointed when the need for the KEDO reactors to receive external power from the grid is considered. The two KEDO reactors consume in-house about 180 MW(e). This load is required to operate the four large primary coolant pumps in each reactor, the feedwater pumps, and all other lighting, air conditioning, and various equipment needs. The in-house power supply needs to be of high quality and stability so as not to interrupt, slow down, or shut down any continuously operated, electrically driven equipment. If, due to grid problems unrelated to the reactors, the network voltage or frequency sags below pre-determined safety margins, some electrical apparatus may not operate and may need to be shut down. This could start a sequence of events leading to a full-plant shutdown, further exacerbating the initial grid problem. In the extreme, disruption of off-site power could, if no other countermeasures are available, lead to various nuclear accident chains. In the more likely event, a prompt shutdown of a reactor due to inadequate off-site power supply could lead to a major electric grid operations disruption, and, in the extreme, to a large-scale network collapse. It is evident that just as the new plants affect grid operations and stability, so does grid stability affect the operation of the new plant. KEDO is negotiating with the DPRK the provision of in-house load from the DPRK's 220-kV network. Maintaining the required high quality of the external power supply (minimizing voltage and frequency fluctuations) is the challenge here. Should external power within the acceptable voltage and frequency ranges not be provided, KEDO may have to install its own power supply on site in the form of a gas turbine, additional emergency diesel generators, or solid-state rectifiers, or AC-DC-AC converters to improve the shape and quality of the grid-supplied power. All these options would further increase the cost of the project and might delay completion date, with associated verification consequences.

3.7 ROK Energy Development Issues

The KEDO project is of value to the ROK for obvious non-proliferation and political considerations, discussed elsewhere in this report. Additional energy development issues, however, provide the ROK with further justification for the project. These issues are briefly reviewed here because they could affect judgments regarding timing and verification issues.

First, the ROK is embarked on a significant nuclear-power expansion program. There are, however, not enough sites available in the ROK in which to build the number of new nuclear plants proposed. **Figure 3-6**[10] includes a list of potential new ROK plants, several of which do not yet have site designation.[11] It may make sense, with the general warming of relations between the ROK and the DPRK, and as a part of a long-term plan to interconnect the infrastructures of the two countries, for the ROK to build some of its future nuclear plants in the DPRK, ship some of the power south, and use the electricity sales revenues to pay the construction costs in the DPRK sites. Should such a program materialize, the KEDO project would be but the first of its kind, with other similar projects (built under bilateral ROK-DPRK agreements) to follow. The creation of the special ROK-DPRK currency-clearing mechanism, which applies to financial settling of bilateral transactions between the two countries only, may ease inter-Korean joint projects, so long as all payments are ultimately guaranteed by the ROK. Such a

Table 3-1. Status of Nuclear Power Plants in Korea (solid circles = in operation, half-solid = under construction, open = in planning)

Plant	Unit	Rx. Type	Capacity (Mwe)	Reactor	Manufacture TG	Commercial Operation	Remarks
Kori	Unit 1	PWR	587	WH	GEC	1978.4	__Turnkey
Kori	Unit 2	PWR	650	WH	GEC	1983.7	__Turnkey
Kori	Unit 3	PWR	950	WH	GEC	1985.9	__Non-Turnkey
Kori	Unit 4	PWR	950	WH	GEC	1986.4	__Non-Turnkey
Yonggwang	Unit 1	PWR	950	WH	WH	1986.8	__Non-Turnkey
Yonggwang	Unit 2	PWR	950	WH	WH	1987.6	__Non-Turnkey
Yonggwang	Unit 3	PWR	1,000	KHIC/CE	KHIC/GE	1995.3	__Non-Turnkey
Yonggwang	Unit 4	PWR	1,000	KHIC/CE	KHIC/GE	1996.1	__Non-Turnkey
Yonggwang	Unit 5	PWR	1,000	KHIC/CE	KHIC/GE	2001.6	__Non-Turnkey
Yonggwang	Unit 6	PWR	1,000	KHIC/CE	KHIC/GE	2002.6	__Non-Turnkey
Ulchin	Unit 1	PWR	950	Framatome	Alstome	1988.9	__Non-Turnkey
Ulchin	Unit 2	PWR	950	Framatome	Alstome	1989.9	__Non-Turnkey
Ulchin	Unit 3	PWR	1,000	KHIC/CE	KHIC/GE	1998.6	__Non-Turnkey
Ulchin	Unit 4	PWR	1,000	KHIC/CE	KHIC/GE	1999.6	__Non-Turnkey
Wolsung	Unit 1	PHWR	678.7	AECL	NEI/Parsons	1983.4	__Turnkey
Wolsung	Unit 2	PHWR	700	AECL/CE	KHIC/GE	1997.6	__Non-Turnkey
Wolsung	Unit 3	PHWR	700	AECL/CE	KHIC/GE	1998.6	__Non-Turnkey
Wolsung	Unit 4	PHWR	700	AECL/CE	KHIC/GE	1999.6	__Non-Turnkey
New	Unit 1	PWR	1,000	Unspecified	Unspecified	2003.6	_
New	Unit 2	PWR	1,000	Unspecified	Unspecified	2004.6	_
New	Unit 3	PWR	1,000	Unspecified	Unspecified	2005.6	_
New	Unit 4	PWR	1,000	Unspecified	Unspecified	2006.6	_
New	Unit 5	PHWR	700	Unspecified	Unspecified	2006.3	_

construction program of ROK reactors in DPRK sites would further increase the number of nuclear facilities located on the East Sea, as discussed previously.

Second, KEPCO is embarked on large-scale nuclear plant standardization programs, starting with the KSNP program and extending to the 1,300-MW(e) Korea Next-Generation Reactor (KNGR), now in the design and licensing stages. KEPCO would like each of its nuclear plants built in the DPRK to be identical to its existing plants in the ROK, save for minimal site-specific modifications. A standardization program would ease the licensing burden on the regulatory agencies, reduce plant capital cost, simplify operations maintenance and refueling procedures, and reduce the annual electricity production costs. In this context, the possibility that General Electric Company (GE) will not allow the KEDO project to use GE-designed turbines, as they were used in all other ROK KSNP reactors, would deal a blow to the KEPCO standardization program in its first application beyond the ROK borders. GE is concerned with the lack of adequate regulation governing third-party nuclear liability issues in the DPRK, as discussed in Chapter 2. Should these issues not be resolved, another turbine manufacturer would have to provide the turbine generators for the KEDO reactors, thus making them different from all other ROK-located KSNP reactors that use the GE turbine, manufactured by Hanjung under license in the ROK.[12]

KEPCO has targeted various East Asia nuclear markets, particularly the PRC as potential opportunities to export the standardized KSNPs. The KEDO project is perceived by KEPCO to be the first example of building standardized KSNPs outside the DPRK, thus serving as a reference plant for future third-party sales. Should different turbines be used in the KEDO reactors, as compared with the ROK KSNPs, the value of the KEDO project as a demonstration/reference plant for further potential exports, as well as serving as a lead project for other KSNPs to be built in the DPRK, would diminish.

Chapter 3 Notes

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4. Nuclear Engineering International 1997 World Nuclear Industry Handbook, Wilmington Business Publishing, Ruislip, U.K., 1997.

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8. Lowell Feld, U.S. Energy Information Administration, North Korea Country Analysis Brief, Washington, D.C., June 21 2000.

9. Peter Hayes, Nautilus Institute for Security and Sustainable Development, DPRK Energy Dilemmas and Regional Security, Presentation to the Asia / Pacific Research Center, Stanford University, Stanford CA, October 10, 2000.

10. Korea Electric Power Corporation, Korean Standard Nuclear Power Plant (KSNP), Seoul, Korea, 1996.

11. The KSNP program now extends over the Yeonggwang 3 and 4 plants—the pre-series, Ulchin 3 and 4 plants—the reference units, Yeonggwang 5 and 6, Ulchin 5 and 6, the New (Shin)-Kori 1 and 2, and the KEDO reactors. Further nuclear plants construction in the ROK may be based on the newer KNGR plants for which no sites have yet been designated. While two (or four) more units may ultimately be built in the New Kori site, and the New (Shin)-Wolsung site may contain four new Canadian CANDU-9 reactors, no other nuclear sites have been dedicated in the ROK.

12. Hanjung (Korea Heavy Industries and Construction) is the design and manufacturing contractor for the Nuclear Steam Supply System (NSSS) and the Turbine Generator (TG). Should GE prohibit Hanjung from using its technology for the KEDO project TGs, Hanjung may need to license a new TG technology from another vendor, e.g., one of the Japanese manufacturers Toshiba, Hitachi, or Mitsubishi Heavy Industry (MHI). Both Toshiba and Hitachi design and build TGs for GE-designed BWRs built under license in Japan. While Toshiba and Hitachi have close working relations with GE and are licensors of GE technologies, they have not built PWR-type TGs that operate at different pressure and temperatures than BWR turbines. MHI does design and build PWR-type TGs, however, they are not familiar with GE equipment. Should the TG technology finally chosen for the KEDO reactors be different from that used for other KSNP plants, this will make the KEDO reactors one of a kind and cause major changes in the entire Balance of Plant (BOP) design. These may include redoing the entire BOP heat balance, sizing up of equipment items, and changing the dimensions and the design of the TG building. The changes required in the BOP may place the BOP on the construction critical path and may delay completion of the entire KEDO Project and cause further delays in meeting some of the DPRK’s non-proliferation obligations, tied to the reactors’ completion dates.

CHAPTER 4
Safeguards on the KEDO Reactors

4.1 Introduction

This chapter begins with a description of the standard KSNP reactors deployed in the ROK and proposed for the KEDO project at the Kumho site in the DPRK. The parts of the reactor plant relevant to the safeguards program are discussed so as to provide the proper context for the safeguards discussion that follows. Most of this chapter then describes in detail the IAEA safeguards program as applied to a KSNP-type of nuclear-power plant. In this discussion, we assume that the safeguards program now applied to the ROK's nuclear plants will equally apply (at the least) to the similar reactors in the DPRK. The description of the safeguards program will stress both the accounting process and the measurement process during normal operation and during refueling outages. We conclude the chapter with a discussion of additional measurements and inspections possible under the IAEA safeguards agreement now in force with the DPRK, together with a brief assessment of other verification measures.

4.2 Project Organization to Supply the KEDO Reactors

Figure 4-1 is a schematic organization chart for the supply of a standard KSNP reactor in the ROK.[1] This figure depicts the contractors' organization assembled to supply a KSNP reactor in the ROK. Since the signing of the Turn Key Contract (TKC) between KEDO and KEPCO in December 1999, this organization chart applies equally to the KEDO reactors' project with the following modifications:

1. KEPCO has assumed the role of the general contractor for the Kumho Site Nuclear Project, with KEDO being the overall owner for whom KEPCO manages the project. This arrangement is different from all other KSNP projects where KEPCO is both the owner and the general contractor.

2. KOPEC (Korea Power Engineering Company) has assumed sole Architect-Engineering (A/E) responsibility for the KEDO reactors subcontracting to KEPCO and has canceled its consulting contract with the U.S. firm of Sargent & Lundy (S&L). S&L was the original A/E of Yeonggwang 3 and 4 (the pre-KSNP plants) and (in a reduced capacity) the remainder of the KSNP reactors.

3. Hanjung (Korea Heavy Industries and Construction) remains the design and manufacturing contractor for the Nuclear Steam Supply System (NSSS) and the Turbine Generator (TG). However, the TG to be used in the KEDO reactors may not be based (under license) on the General Electric (GE) turbines like the rest of the KSNP plants because GE did not obtain the measures of relief it sought from third-party liability.

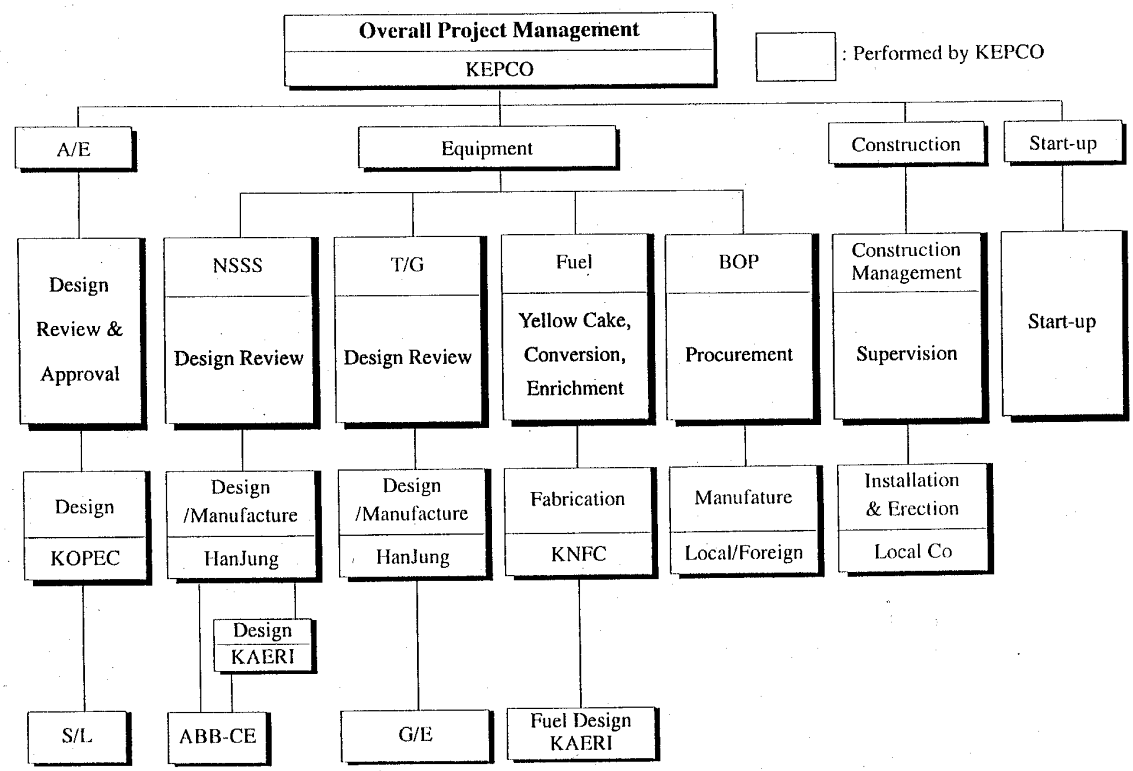


Figure 4-1. Organization chart for the supply of a standard KSNP reactor.

4.3 Description of the KEDO Reactors

The KEDO reactors are the KNSP design, a modification the System 80 design of Combustion Engineering Company (formerly ABB/CE, now Westinghouse Electric Corporation, a unit of British Nuclear Fuel Ltd.). The System 80 design, in turn, is based on an improved and scaled-down design of the Palo Verde station in Arizona. KEPCO has built two plants of the System 80 design—the Yeonggwang 3 and 4 units. This design was further enhanced by KEPCO, adjusted to Korean conditions, and renamed the Korean Standard Nuclear Plant. The first two units of the KSNP series of standardized plants were the Ulchin 3 and 4 plants, the reference plants of the series. Four other plants of this series are under construction in the ROK; two additional ones were announced and the two KEDO reactors, planned as identical to other KSNP units, are further extensions of this ROK series.

A description of the KNSP plants is available in References 1-3 (see the End Notes for this chapter) as well as in many other nuclear-engineering publications. The discussion here is limited to the parts of the plant relevant to the refueling operations and to which safeguards arrangements apply. A side cut of a KSNP building is shown in **Figure 4-2**.[1] The reactor building is shown in the center, with the adjacent fuel building on the right. The left side of the figure includes the TG building and other Balance of Plant (BOP) facilities, which are essential for the energy-conversion part of the plant, but are not related to the nuclear fuel or to safeguards arrangements. The nuclear reactor itself is in the lower part of the reactor building. During routine operations, the reactor pressure vessel is closed and the entire vessel is immersed in a large water pool.

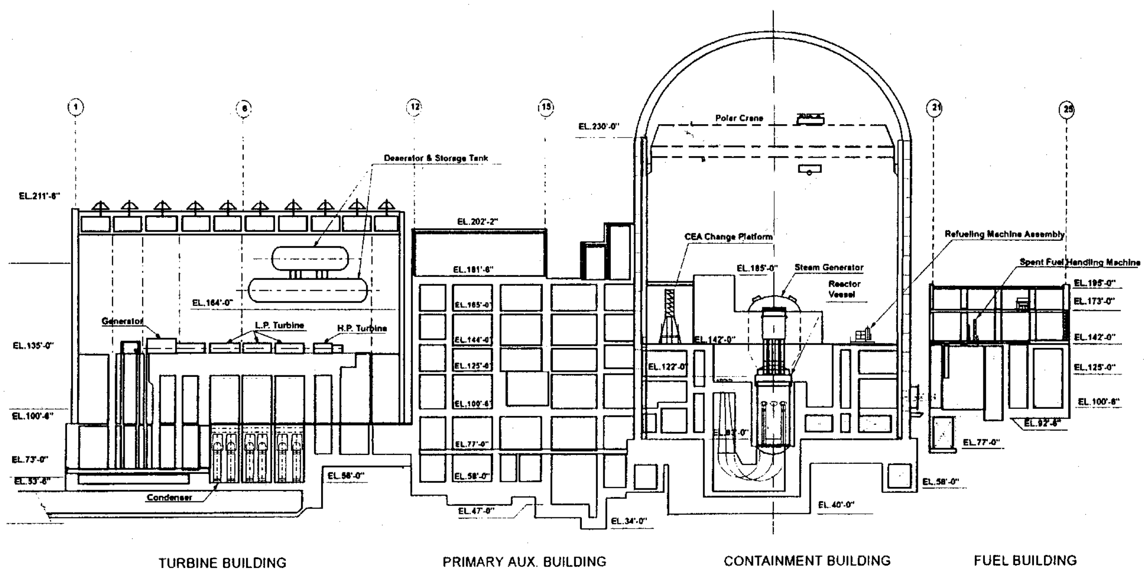


Figure 4-2. Side view of a KSNP building.

During routine operations, access to the reactor building is very limited and tightly controlled access. The two major entry ways into the reactor building are through personnel access port(s), camera-monitored and controlled by the reactor operators, and through the large equipment hatch. The equipment hatch is regularly tightly sealed to completely isolate the reactor building from the outside for safety considerations. Additionally, the IAEA places its own seal on the equipment hatch and installs a remotely monitored camera in the reactor building surveying the equipment hatch area. These two measures are intended to ensure that no large-scale equipment, such as spent-fuel storage casks, can be brought into the reactor building to surreptitiously remove fuel elements from the core.

Fresh fuel elements are brought into the reactor plant and spent fuel elements are taken out of the plant through the fuel building. The fuel building contains the receiving area for the fresh-fuel-element containers, the water pool in which the fresh fuel elements are stored prior to their insertion into the reactor core during the refueling operation, the transfer canal from the fuel building to the reactor building, the spent-fuel storage pool, and the spent-fuel cask loading area.

By far the largest component of the fuel building is the spent-fuel storage pool sized to contain the routine discharges of at least 10 years of operation, plus additional capacity for a full-core discharge in case all the nuclear fuel from the reactor's pressure vessel must be removed to maintain or repair the vessel or its internal components. It is possible through re-racking and installing of neutron-absorbing plates to increase the storage capacity of the spent-fuel storage pool to about 20 years' worth (maintaining the full-core discharge capability) while avoiding criticality concerns. Once the capacity of the spent-fuel storage pool is reached, the spent fuel already in the pool must be removed either to storage pools at other reactors, to an away-from-reactor storage facility, or to dry storage in steel or concrete casks at the reactor site or at a centralized facility. Because the operating life of a KSNP is expected to be at least 40 years and could well be extended to 60 years, the disposition of its spent fuel outside of the reactor building is a matter of safeguards concern. In case of the KEDO rectors, assuming commercial operation by 2010, a detailed plan for disposing of old and discharged spent fuel will have to be in place no later than 2030.

A top-down (footprint) view of a KSNP reactor is shown in **Figure 4-3.**[1] As seen, the parts of the plant of concern to the safeguards program—the reactor building, the fuel building, and the fuel transfer canal are a relatively small part of the overall plant buildings' area. The major part of the plant is taken up by the auxiliary building around the reactor building, and by the TG building.

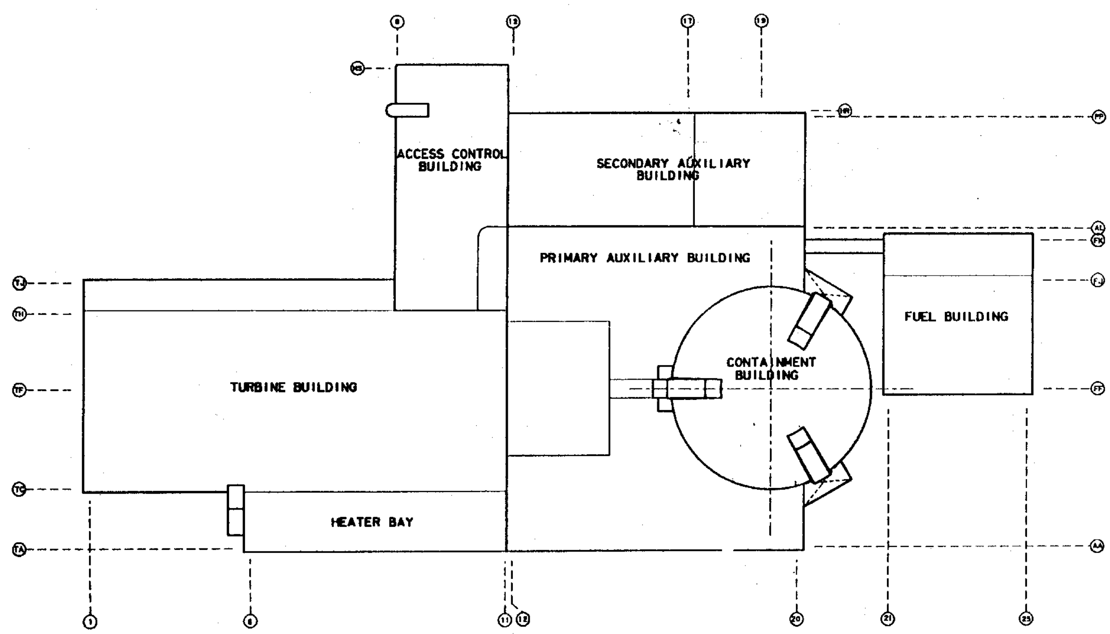


Figure 4-3. A top view of the KSNP reactor.

A particular point of concern to the safeguards program is the horizontal fuel transfer canal located in the lower part of the reactor building and connected to the bottom part of the spent-fuel storage pool in the fuel building. The IAEA installs a seal on the moveable bridge on top of the fuel transfer canal. A remotely monitored camera is installed by the IAEA on the fuel building's wall facing the fuel transfer canal and the IAEA seal on the bridge. Thus, any surreptitious attempt to move spent fuel through the transfer canal from the reactor to the fuel building, or to remove fuel from the fresh or spent fuel pools in the fuel building, will be detected.

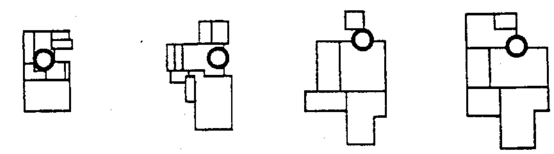
Figure 4-4 is a schematic view of the of the primary system equipment layout in the reactor building.[2] The equipment arrangement of the System 80 KSNP reactor is unique among PWR designs. This design is built on two large steam generators, each connected through a "hot leg" pipe to the reactor vessel. The discharge from each steam generator is divided and sent through two large primary pumps through two large pipes, "the cold legs" back into the reactor vessel. Most 1,000-MW(e) PWRs are built on a three-loop design, with each of the three loops containing its own steam generator. The System 80 design with only two loops is distinguished by having two very large steam generators. Because the equipment hatch is sized to pass through the largest equipment item in the reactor building, the System 80 design has a large hatch capable of passing through a large steam generator and is certainly capable of passing through even the largest sized spent-fuel storage cask.

KOREAN STANDARD PLANT

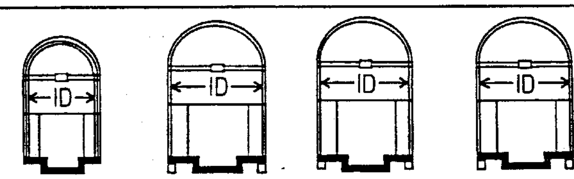
Development of Korean PWRs

	Kori 1	Kori 3	Yonggwang 3	KSNP
Gross capacity (MWe)	587	950	1000	1000
Comm op. date	1978.4	1985.9	1995.3	

General layout

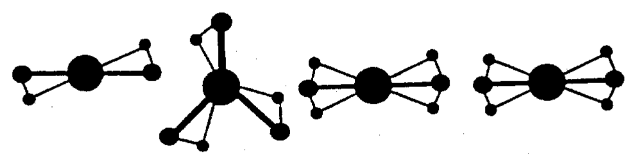


Containment building



	Kori 1	Kori 3	Yonggwang 3	KSNP
Type	Steel containment	Pre-stressed concrete	Pre-stressed concrete	Pre-stressed concrete
ID (m)	32	39.6	43.9	43.9*
Design pressure (lb/in² (g))	43	60	54	57*
Free volume (m³)	41 000	61 000	76 000	76 000

Reactor coolant loops



	Kori 1	Kori 3	Yonggwang 3	KSNP
Loops	2	3	2	2
No. of fuel assemblies	121	157	177	177
Reactor ID (cm)	132	157	162/396.9	162/396.9
Inlet/outlet temperature (°C)	282.6/320.2	291.9/326.9	295.8/327.3	295.8/327.3

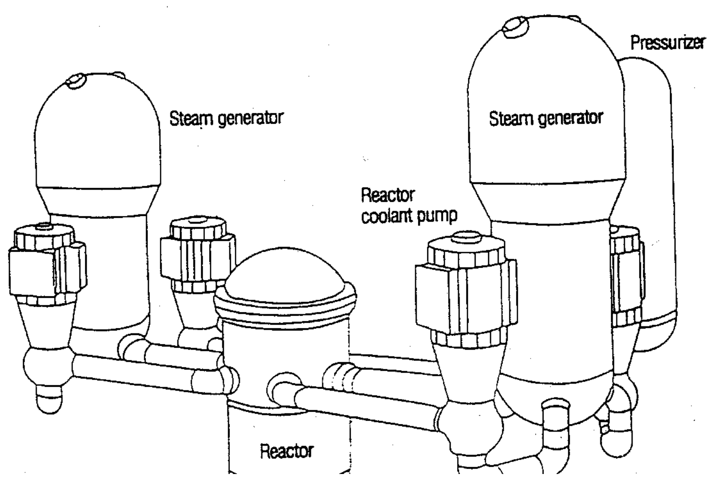


Figure 4-4. Schematic of the primary system layout in the reactor building.

Figure 4-5 shows the internal layout of the KSNP reactor vessel.[2] The reactor core, in which the fuel elements are contained, is located in the lower half of the pressure vessel below the two outlet nozzles of the two hot legs and the four inlet nozzles of the cold legs. The water in the primary system (the reactor vessel, the tubes side in the two steam generators, the four primary pumps, and the pressurizer) enters the reactor vessel through the inlet nozzles, flows down around the circumference of the vessel, enters the reactor core area from the bottom part and flows upwards through the core volume inbetween the fuel elements. Water is heated on its passage through the core and then exits the reactor vessel through the two hot legs on its way to the steam generators. The steam generators produce steam in the secondary system (the vessel side of the two steam generators, the turbine generator, condenser, and the feedwater heating system) that rotates the TG machinery to generate electricity. **Figure 4-6** summarizes design data for the KSNP reactor.[2]

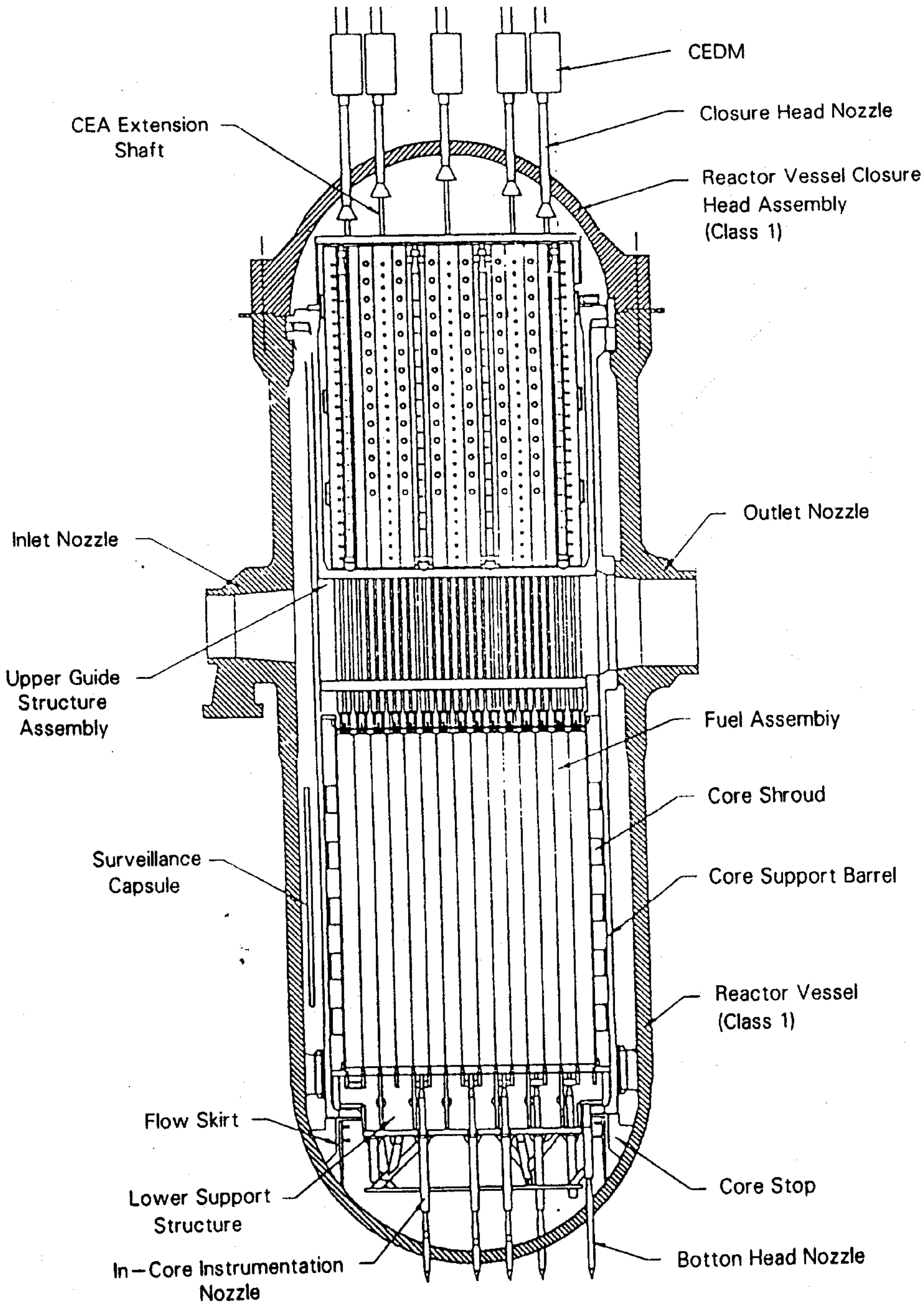


Figure 4-5. Internal layout of the KSNP reactor vessel.

The upper part of the reactor-vessel internals contains the control rods' guide tubes and the portions of the control rods withdrawn from the reactor core to achieve criticality in the core and maintain a stable nuclear chain reaction. The upper part of the vessel is also filled with primary system water, which provides extra water volume in the vessel for emergency cooling purposes, increasing the safety margins of the entire reactor system. The control rods are connected though the top of the reactor vessel with the Control-Rod Drive Mechanisms (CRDMs) that govern the vertical movements of the rods in and out of the reactor's core.

KOREAN STANDARD PLANT

Characteristics of the Korean Standard Nuclear Power Plant

Reactor	
Type	PWR
Thermal output	2815 MWt
Coolant flow rate	121.5×10^6 lb/h
Design pressure	2500 lb/in² (a)
Operating pressure	2500 lb/in² (a)
Design temperature	650°F
Inside diameter at shell	162 in
Overall height	48 ft
Fuel	
Number of fuel assemblies	177
Number of UO_2 fuel rods per assembly	236 (16 × 16)
Fuel weight	188 609 lb
Core height (active)	150.0 in
Core diameter (equivalent)	123.0 in
Clad material	Zircaloy-4
Clad thickness	0.025 in
Reactor coolant system	
Number of loops	2
Hot leg/cold leg	42/30 in
Reactor inlet temperature	564.5°F
Reactor outlet temperature	621.2°F
Total coolant volume	11 315 ft³
Control rods	
Number of control assemblies	73
Number of rods per assembly	4 or 12
Material (full/part strength)	B_4C/Inconel
Steam generators	
Type, number of units	Vertical U-tube, 2
Steam flow per steam generator	6.364×10^6 lb/h
Steam pressure at full power	1070 lb/in² (a)
Steam temperature at full power	550.5°F
Maximum moisture	0.25%
Feedwater temperature	450°F
Reactor coolant pumps	
Number	4
Motor/type	AC induction/ vertical, centrifugal
Design capacity	82 500 gal/min
Design head	340 ft
Containment	
Type	Prestressed cylindrical concrete with steel liner
Inside diameter	144 ft
Height	216 ft
Free volume	2.73×10^6 ft³
Liner thickness	0.144in
Turbine	
Number	4 (high 1, low 3)
Type	Serial 6 flow arrangement
RPM	1800
Generator	
Number, type	1, 4 poles (1800 RPM)
Voltage	22 kV, 3 phases
Frequency	60 Hz
Net electrical output	1000 MWe
Condenser	
Number, type	3, once-through sea water cooling
Pump type	Vertical, centrifugal 50% × 3

Figure 4-6. Design data for the KSNP reactor.

4.4 Refueling Operation in the KEDO Reactors

Of particular interest from a proliferation perspective is the time required to access the reactor core and its fuel assemblies. This takes at least two to four days with a relatively experienced crew and may take longer. First, it takes about two days for the reactor to cool and depressurize and for the intense radioactivity to subside to tolerable levels. Second, the vessel head and CRDM mechanisms must be removed. This takes an additional one-half to two days.

The time between refueling (also called the cycle time) depends on a number of variables, including the design burnup (a measure of the total energy supplied by a given mass of fuel), and the design of the fuel and reactor. Most PWRs operating today are transitioning from a one-year cycle to an eighteen-month cycle and some to a two-year cycle. These cycle times are "nominal" and can vary in practice with power demand or to take advantage of personnel availability. Current PWRs of the System 80 KNSP vintage are designed to operate at a design burnup of 45 to 50 MWD/kg, and there is interest in increasing these burnup levels still further to about 70 MWD/kg. The transition to higher design burnup levels and longer residence time in the core (longer cycles) means that over time a smaller amount of spent fuel is generated that has to be stored, monitored, and disposed of.

One-third of the core is replaced at each refueling. Fuel will normally reside in the reactor's core for three full cycles, four and one-half years, before being discharged as spent fuel. In practice, both the refueling schedule and the fraction of the core replaced each time can vary between cycles depending on the operating history of the plant.

Generally, the reactor is refueled by:

1. Shutting the reactor down, allowing it to cool, and removing the pressure vessel top (or head) and the associated equipment.

2. Removing the oldest fuel from the reactor. This is the fuel that has resided in the core for three full cycles, and therefore has achieved its nominal design burnup. This fuel is generally in the center of the core. On removal, this fuel is sent to the spent-fuel storage pool.

3. Shuffling the remaining in-reactor fuel to different positions within the core. This is done to level the reactivity and power distribution in the core.

4. Inserting the fresh fuel. The fresh fuel is inserted into the outer periphery of the core. The higher reactivity of the fresh fuel compensates for the lower neutron flux and the higher neutron leakage rate from the core at the periphery.

5. Reinstalling and bolting the pressure vessel head and reconnecting the CRDMs.

6. Restarting the reactor.

In the U.S., the shortest reactor refueling operation has been accomplished in just 16 days (the current U.S. record), although the average is approximately 34 days. The actual time required to refuel a reactor varies depending on the type of reactor, the skill and experience of the operators, and the maintenance (both scheduled and unexpected) required during the outage.

As seen in Figure 4-6, the reactor core contains 177 assemblies. Each one-third core refueling results in 59 assemblies withdrawn from the core as spent fuel and 59 fresh fuel assemblies inserted into the core. **Figure 4-7** is a schematic drawing of a fuel assembly.[3]

Each assembly weighs slightly over 600 kilograms (more than half a ton) and contains 236 long- and small-diameter fuel rods arranged in a square 16 x 16 lattice with an empty "water hole" in the center. Each fuel rod contains a number of cylindrical fuel pins or pellets stacked in a column and held in a zircalloy tube.

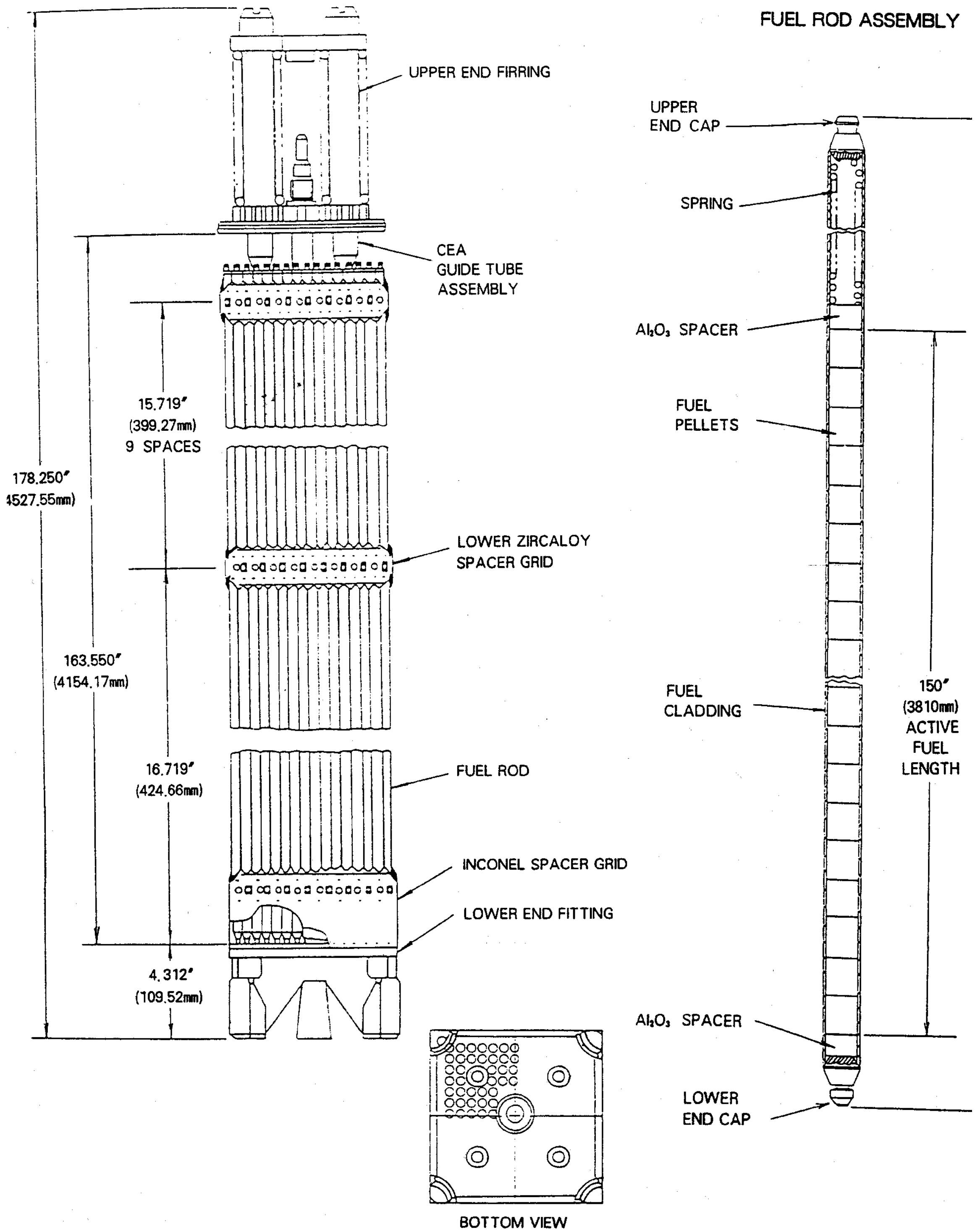


Figure 4-7. Schematic of a fuel assembly.

During refueling, each fuel assembly is inspected before being inserted or reinserted into the reactor. The level of detail to which each assembly is inspected can vary. For example, fuel that has been in the reactor for two cycles may be inspected more thoroughly than fuel in for only one cycle. If there are indications of problems (such as detection of fission-product gases released from a leaking fuel pin), a more rigorous inspection may ensue. Fuel that is damaged or otherwise suspect is not reinserted into the reactor, but sent to the spent-fuel storage pool. Depending on the type and extent of damage, the rejected fuel assembly may be placed in an intermediate sleeve (and the entire assembly placed in the spent-fuel storage pool) to minimize contamination of the spent-fuel storage pool. Alternately, a leaking fuel rod can be removed from an assembly (underwater) and a new rod inserted so that the repaired assembly can be reinserted into the core.

A reactor operator normally has a supply of fresh fuel on hand. Immediately prior to a refueling, there is at least a 1/3 core of fresh fuel available. This stock is accumulated over the course of some months, as it was not likely delivered in a single shipment. Because of the possibility of defective fuel, reactor operators normally keep a small stock of additional (beyond that required for the next refueling) fresh fuel on hand. Partial refueling may occur between normal fueling outages. Although unusual, this can occur if, for example, failed fuel is detected during operation (usually by detection of fission-product gases such as iodine).

The spent fuel assemblies discharged from the reactor are moved by the charge/discharge machine away from the pressure vessel and place in a horizontal position on a trolley that carries them through a transfer canal (a tunnel) leading from the reactor building to the fuel building. **Figure 4-8** is a schematic of the fuel transfer process.[2] Once in the fuel building side of the canal, the fuel assembly is brought again to an upright position and is carried underwater to its storage position in the spent-fuel storage pool. The position and identity of each assembly in the storage pool are recorded and verified by the IAEA safeguards inspectors on their periodic inventory-verification visits to the plant.

Spent Fuel and Plutonium

LWRs fueled with LEU (essentially all of them) inescapably produce plutonium as a byproduct. The quantity and quality of the Pu produced are both affected by plant operations, with the principal variable being the total irradiation of the fuel in the reactor. Fuel irradiation is referred to as *burnup* and is a measure of the total energy produced by a unit mass of fuel. Fresh LEU fuel has no Pu, and the total amount of Pu in the fuel increases with increasing burnup.

Pu is produced primarily by neutron capture in ^{238}U, the most abundant isotope of uranium in LEU fuel. This produces primarily ^{239}Pu, the isotope best suited to weapons applications. However, the quality of the Pu produced (measured as the fraction that is ^{239}Pu) decreases with increasing burnup. As the reactor continues to operate (and burnup increases), some of the Pu itself captures additional neutrons; some of it then fissions, contributing a significant amount to the total energy generated by the reactor, and some is converted to the so-called “higher isotopes” of Pu. The higher even-isotopes of Pu, in particular, do not fission effectively in a thermal reactor and thus accumulate (at the expense of the ^{239}Pu). Other nuclear reactions also contribute to the production of troublesome isotopes (such as ^{238}Pu), with the fraction of these isotopes also increasing with increasing burnup. These other isotopes of Pu may themselves be used in a weapon, but they make design, manufacturing, handling, and reliability of a weapon containing such isotopes difficult.

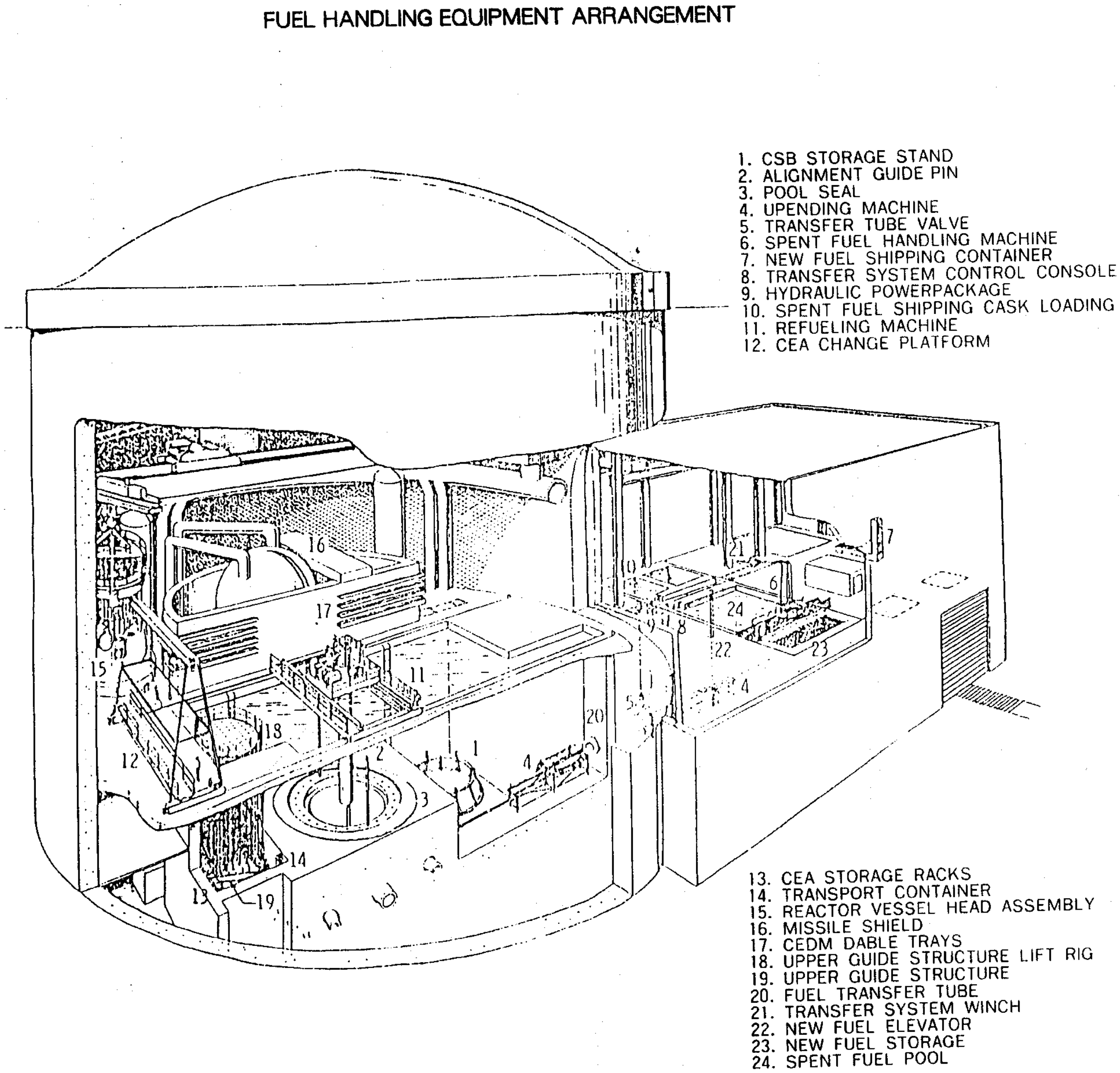


Figure 4-8. Fuel transfer process.

4.4.1 The Special Problem of the Beginning-of-Life and End-of-Life Fuel Discharges

A reactor can be considered to have three distinct phases in its overall life cycle: beginning of life (BOL), equilibrium, and end of life (EOL). Most of the reactor's lifetime is in the equilibrium part of the life cycle where normal spent fuel is put in the reactor, remains for three cycles, and then is removed as spent fuel.

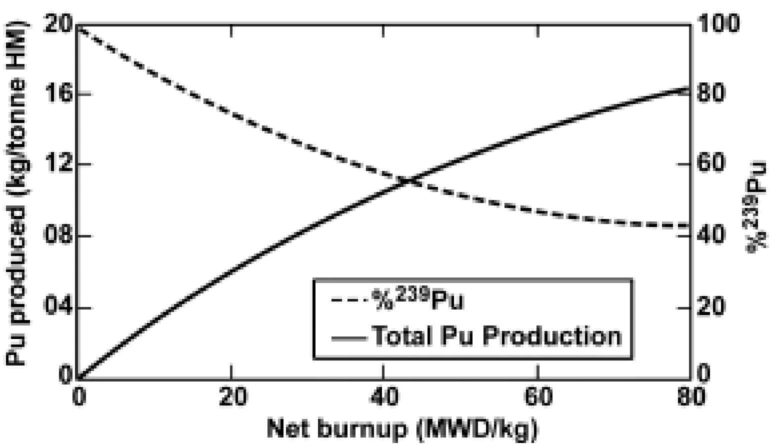
Early in the reactor's operating life (the BOL), much of the fuel in the core is very fresh, without the buildup of fission-product poisons, plutonium and other elements that affect the reactivity of the fuel. For this reason, some of the BOL fuel is supplied with lower enrichment than fuel used later in the equilibrium part of the lifecycle. In the "initial core," the lowest enrichment fuel goes into the center zone of the core, medium-enrichment fuel goes into the intermediate zone, and nominal enrichment fuel is placed in the outer zone. This arrangement mimics the reactivity distribution of a core later in its life.

At the first refueling, the central zone of the core is removed, and sent to the spent fuel pool, just as normal spent fuel. However, this fuel has been in the reactor for only one cycle, and therefore has only 1/3 the "nominal" burnup. As **Figure 4-9** in the sidebar shows, reduced burnup introduces two effects that have important implications for proliferation:

- The total quantity of plutonium in that spent fuel is reduced because of the reduced burnup, but
- The quality of the plutonium for weapon use is higher than for full-burnup spent fuel.

Similarly, at the second refueling, the spent fuel removed has seen only two cycles, so the quantity and quality of its plutonium lies roughly mid-way between that of one-cycle and three-cycle or full-burnup spent fuel. Roughly, the BOL portion of the reactor lifetime can be considered to last for the first three cycles.

Figure 4-9. The relationships between plutonium production, quality, and burnup can be seen in the figure. At very low burnups, very little plutonium is produced but that produced is primarily ^{239}Pu. At higher burnups, the total amount of plutonium produced becomes substantial, but the fraction of ^{239}Pu decreases significantly.



A similar situation occurs at the end of the reactor life. At the next-to-last refueling, the fresh fuel inserted into the reactor will only remain in the reactor for two cycles, and that inserted during the last refueling will remain in the reactor for only a single cycle. The implications of the EOL part of the lifecycle are similar to those at the BOL: some of the EOL spent fuel will have seen only one or two cycles, and thus has plutonium of higher quality, albeit lesser quantity.

Thus, three "types" of spent fuel are generated as a result of normal plant operations:

1. Of greatest concern is the spent fuel discharged during the BOL and EOL, which has much less than nominal burnup. The earliest discharged BOL fuel has seen only one cycle of operation and will only have 12 to 15 MWd/kg burnup (assuming a "nominal" 45 MWd/kg design burnup). The first cycle discharges spent fuel containing approximately 100 kg of plutonium, of which over 80% is ^{239}Pu. The one-cycle EOL spent fuel will have similar characteristics.
2. The second refueling discharges fuel at approximately 30 MWD/kg, yielding some 175 kg of plutonium containing roughly 65% ^{239}Pu. The two-cycle EOL spent fuel will also have similar characteristics.
3. Each equilibrium refueling (45 MWd/kg) discharges fuel containing about 288 kg of plutonium with about 57% ^{239}Pu content.[4]

Due to their higher ^{239}Pu quality (and thus increased attractiveness for weapon use), both the BOL and EOL discharged fuel assemblies merit special attention and verification efforts.

4.5 IAEA Safeguarding of Nuclear Fuel in the KEDO Reactors

The following discussion of IAEA safeguards aims at describing the actual implementation of safeguards agreements related to nuclear-power plants such as the KEDO reactors. The application of safeguard measures to commercial LWRs and particularly to 1,000-MW(e)-class PWRs such as the KSNP reactors is described in References 5 and 6, both of which relate to safeguarding nuclear-power plants in the Korean Peninsula. We assume that the safeguard measures applied to the ROK's KSNP reactors will apply as a minimum to the KEDO reactors. In fact, the IAEA might well insist on further enhancements within its agreements with the DPRK, and some of these are described in Section 4.6 and Reference 7. Until the appropriate Facility Agreements are signed between the IAEA and the DPRK, we will not know what these will be. An IAEA perspective on the general type of IAEA safeguard measures applied to typical LWRs is presented in References 5 and 8. An ROK perspective on developing a lead project on safeguard measures enhancements that will equally apply in the ROK and the DPRK, and which could in fact apply to all other LWRs is presented in Reference 6. Some problem areas in implementing safeguard measures related to the AF are discussed in Reference 9, and the IAEA safeguards requirements related to the DPRK nuclear program are discussed in Reference 7.

4.5.1 The Safeguards Goals for Quantity and Timeliness

The standard IAEA approach to LWR plant safeguards for signatories to the NPT is the IAEA "Model Safeguards Agreement," INFCIRC 153 of 1971, and its specific application to the DPRK is documented in IAEA INFCIRC 403 of May 1992. In general, the purpose of LWR-type safeguards agreements is to verify that nuclear materials are not diverted to producing nuclear weapons or other nuclear-explosive devices. The verification process is achieved through inspection measures described below. The purpose of these inspections is two-fold: first, the Quantity Component is meant to provide assurance that there has occurred no diversion of Significant Quantities (SQs) of various nuclear materials over a Materials Balance Period (MBP); and second, the Timeliness Component is meant to provide timely detection against abrupt diversion of SQs of nuclear materials within specified time periods between periodic inspections of the LWR. The inspection goal for each LWR is attained if all the quantity and timeliness criteria specified in the Facility Agreement signed between the IAEA and the host nation of the specific LWR are met.

In terms of the timeliness criterion, the IAEA defines the frequency of inspections as:

- one year for fresh LEU fuel (FF),
- three months for reactor core fuel containing bred plutonium (CF),
- three months for spent LWR fuel outside the reactor core (in the spent-fuel storage pool) and containing plutonium.

The choice of the time period between inspections is predicated on the IAEA's assumptions regarding the time required from diversion through fissile-material refining to the manufacturing of a completed nuclear-explosive device. Based on the details of the specific Facility Agreement, the IAEA must perform interim visits by IAEA inspectors at the frequencies mentioned above to ensure that no diversion of nuclear materials has occurred during the period since the last inspection.

The IAEA meets its safeguarding obligations through both items accounting and through Containment and Surveillance (C&S) measures. Item accounting includes record checking at various locations, physical identification, counting, non-destructive measurements, and examinations to verify the integrity (over time) of different items. In a nuclear plant, the items inspected and verified are the fuel assemblies, and in few cases of leaking pins—individual fuel rods. C&S measures complement the accounting and inspection procedures by providing seals at critical points in the reactor plant to prevent diversion-related unauthorized entry, and by operating surveillance systems to detect undeclared movement of nuclear materials, or attempts to tamper with the containment system or the IAEA seals and safeguard devices. The C&S system is particularly applicable to highly radioactive nuclear materials, which cannot be inspected from nearby and thus are remotely monitored. In practice, the C&S system applies mostly to the plutonium-bearing CF in the reactor building and the Spent Fuel (SF) in the spent-fuel storage pool in the fuel building. Both the accounting and the C&S measures, which are the heart of the safeguards regime, are described in the next section.

Significant Quantities (SQs) of nuclear materials are defined as the approximate quantities of materials required to manufacture a nuclear-explosive device. The IAEA has defined a SQ based on direct use of fissile materials as:

- 8 kilograms of plutonium,
- 25 kilograms of ^{235}U contained in Highly Enriched Uranium (HEU),
- 8 kilograms of ^{233}U.

The IAEA further defined the SQ for uranium requiring additional processing (indirect use) as:

- 75 kilograms of ^{235}U contained in LEU,
- 10 tons of natural uranium,
- 20 tons of depleted uranium.

These various forms of uranium require further enrichment to extract adequate amount of fissile ^{235}U for direct use in weapons production.

4.5.2 The Safeguards Accounting Process

The IAEA safeguards regime is basically a large-inventory accounting system, systematically applied to account for all nuclear materials at all the declared nuclear facilities in each country. Full inventory (statistically complete) is taken at the appropriate frequencies based on the timeliness criteria to ensure that no diversion that could have led to the manufacturing of nuclear-explosive devices has taken place since the last inspection and inventory. In each country, the accounting process starts from the country borders and narrows down to the specific plant and specific Material Balance Areas (MBAs) within each plant. At the country level, the accounting process may include unprocessed or partially processed materials such as natural, enriched or depleted uranium. At the power-plant level, the accounting process deals with specific numbers of assemblies at different locations in differing time periods.

To carry out the accounting process, the IAEA relies first on examinations of records. These include both country reports and specific facility records. The IAEA further:

- checks domestic and international materials transfers,
- attempts to confirm that no unrecorded production of direct use materials (measured in SQ) has taken place,
- confirms the absence of borrowed nuclear materials,
- correlates all the above with the data from its last interim inspection,

- and, out of these data, recreates an updated material balance that accounts for the whereabouts and disposition of all nuclear materials at the time of the specific inspection.

This material balancing process occurs both at the national and at the facility levels with the records from each level aggregating (or dis-aggregating as the case may be) to the other level.

At the facility level, in particular, the IAEA records examination may include several activities as follows:

- Examination of the facility's accounting records such as the general ledger, receipt/shipping records, inventory documentation, etc.
- Examination of the facility's operating records such as the operations logbook, assembly history cards, core fuel maps, pool fuel maps, etc.
- Reconciliation of the accounting records, the operating records, and the results of the last inventory inspection.
- Comparison of the facility records with the country reports and specific notifications, to allow vertical reconciliation.
- Preparation of the summary results of the inventory inspection that will provide the baseline for the next inspection.

The above activities are supplemented by physical inspections and verification examinations of the fresh fuel, the core fuel, and the spent fuel, to make sure that the facility records correspond to the results of the actual inspections on site. At the power plant, this means that the office records related to the number of assemblies at various locations in the plant coincide with the results of the plant inspections and assembly counting on site.

4.5.3 Materials Balance Area in KEDO type Reactors

A KEDO-type, 1,000-MW(e) PWR includes three MBAs over which an inventorying process is undertaken between each periodic inspection and the next. The MBAs include:

- The FF Storage with Key Measuring Point A. This balance is applicable to LEU only. It is based around the FF pool in the fuel building and the reactor core in the reactor building (at refueling outages). This material balance considers new FF brought into the plant, FF on storage at the FF pool in the fuel building and FF loaded into the reactor core during a refueling outage.

- The CF with Key Measuring Point B. This material balance is updated during scheduled refueling outages, which occur in a KEDO-type reactor every 18 months. Special inspections are also held if for any reason the reactor was shut down, the pressure vessel top was removed, and core fuel was discharged. The assembly balance is held between the numbers of assemblies in the core as of the last inspection (CF), the number of spent-fuel assemblies removed from the core (SF), and the number of fresh fuel assemblies added to the core (FF). Core-fuel inventorying has to consider the both enriched ^{235}U in the FF and CF (as well as the unfissioned ^{235}U in the SF), the bred plutonium growth and fissioning in the CF, and the discharged plutonium in the SF.

- The Spent Fuel Pool (SF), with Key Measuring Point C. The spent fuel pool is the most sensitive part of the safeguarding process, considering that at each 18-month interval, an additional 59 SF assemblies are added to the pool, and that the short-lived fission products decay at a fast rate. Within 18 years of operation, close to 600 assemblies will accumulate in a KEDO-type reactor's SF pool, all of which have to be accounted for, based on the timeliness criterion, every three months. As detailed earlier, the first core (BOL) assemblies with high ^{239}Pu fraction are particularly sensitive, especially after its (relatively lower) activity has decayed for 18 years.

The material balance on the SF pool includes:

- the inventory as of the last inspection,
- additional SF discharged from the core in the latest refueling outage (assuming one has occurred since the last inspection),
- SF removed from the SF pool for dry-cask storage on site or to other SF pool,
- SF removed from the pool to a centralized away-from-reactors storage facility,
- SF removed for direct disposal.

The SF material balance has to consider both the plutonium content in the various SF assemblies and the residual ^{235}U remaining in the SF.

In each periodic inspection, described below, a material balance is carried out on each MBA, and it is required that the each of the balances will properly close and that all three balances will correspond to the facility records, taking into account the plant operating history. Given this multi-layered, inventory-taking process, it is now necessary to discuss the C&S process, and following that, the inspection process.

4.5.4 The Containment and Surveillance Process

The C&S measures implemented by the IAEA are aimed at complementing the accounting process by placing seals at strategic locations to prevent access to nuclear materials and by installing surveillance cameras to check for suspicious movements in the reactor or fuel buildings. The IAEA standard method of installing C&S equipment is shown schematically in **Figure 4-10**.[5] The IAEA installs a seal and a surveillance camera in the reactor building, and another seal and a camera in the fuel building. Some variation on this basic scheme involving additional seals also exists, as seen in Figure 4-10. An additional temporary surveillance camera is installed by the IAEA in the reactor hall during a refueling outage.

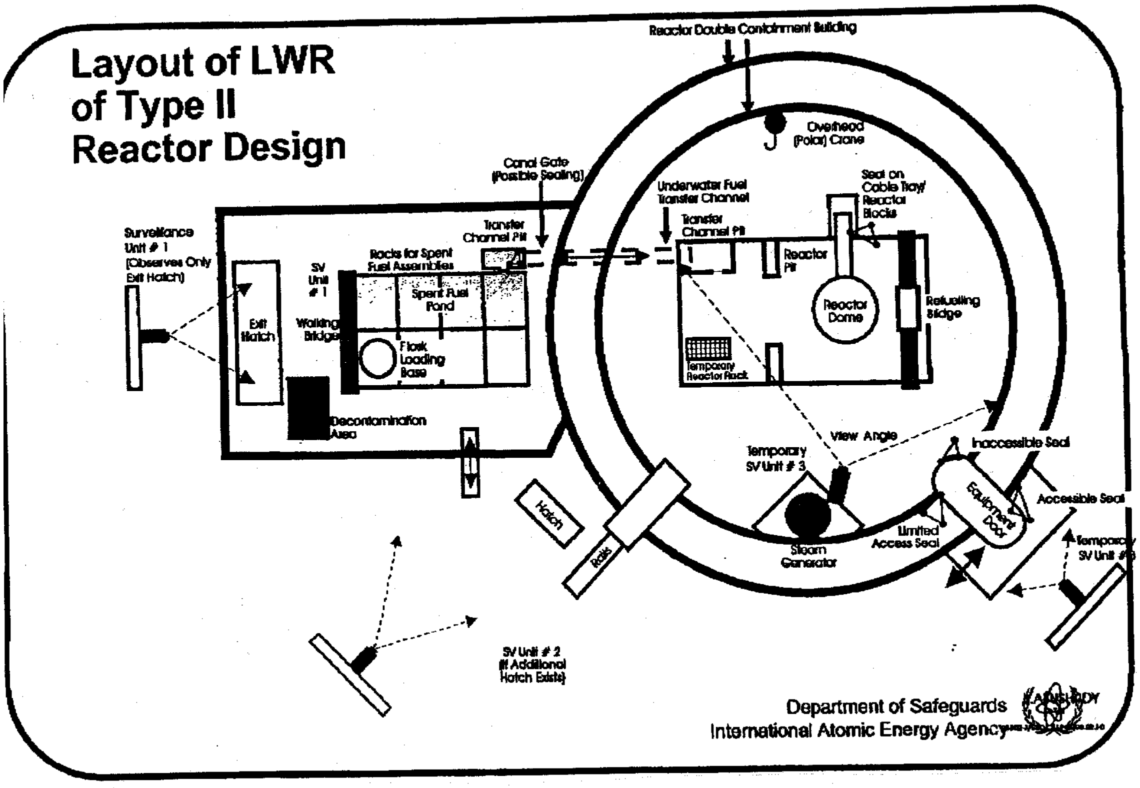


Figure 4-10. Reactor layout showing the containment and surveillance process.

The seal in the reactor building is placed on the large equipment hatch, and the camera is pointed at the hatch. The purpose of observing the equipment hatch is to make sure it is not opened surreptitiously to admit a heavy shielded cask into the reactor hall to remove core fuel or spent-fuel assemblies from the building. Both the CF and SF assemblies being highly radioactive require large-sized holding casks that cannot pass through the narrow personnel access ports and that can only be brought into the reactor building through the equipment hatch.

The seal in the fuel building is installed on the bridge above the transfer canal from the reactor to the fuel building. The purpose of this seal is to reveal any unauthorized use of the transfer canal, for instance, to remove CF or SF fuel from the reactor building to the fuel building. The wide-angle camera on the wall of the fuel building covers the entire fuel pools area, including the fresh and spent fuel pools, the cask-loading and unloading areas, and the transfer canal. This camera tracks and records all movements within the fuel building and can record any unauthorized transfers of fuel in or out of the building or the storage pools.

In some cases, additional seals are placed on the cable tray bridge connecting the reactor pressure vessel top and the side of the reactor building. These seals reveal access to the reactor top, which has to be opened to divert CF or SF from the reactor core. The IAEA does not routinely install a third seal and camera in the plant, within the reactor building and facing the top of the reactor vessel and CRDM assembly, and the cable tray bridge leading to it. During outages, the IAEA does rig a temporary camera in the reactor hall facing the open top of the pressure vessel and records the entire sequence of the refueling operation for later review. Routine installation of a third seal and camera would heighten confidence that the reactor vessel is not being tampered with and is desirable in this case.

Even more desirable is an advanced seal-camera system implemented on a trial basis in three ROK reactors, shown schematically in **Figure 4-11**.[6] This scheme is based on two camera-seal pairs, one installed in the reactor building and the other in the fuel building, as described above. The unique aspect of this scheme is that all cameras and seals are connected via to a server that records the sensors' data and transmits them via an Internet uplink to the IAEA in Vienna every three minutes. The server is located in the fuel building and is placed inside a secured box to prevent tampering. This remote control data-gathering allows a near-real-time inspection of the status of the equipment hatch and the fuel pools areas by the IAEA safeguards experts in Vienna, thousands of miles removed from the actual nuclear plants in the Korean Peninsula. If this proves to work effectively—and all indications are that it will—the IAEA will consider this system as an equipment enhancement package that matured with new technologies, and which should be implemented at all reactors under safeguards. The data-gathering and transmission system should itself be hardened and monitored so that it cannot be spoofed or interfered with without warning.

This experimental program not only provides an immediate view of the sensitive parts of a nuclear plant located anywhere in the world, but is also quite economical in terms of conserving scarce IAEA resources. Installing this system in the KEDO reactors, in parallel with its installation in all the ROK's nuclear plants, would significantly enhance the KEDO reactors' safeguards, particularly if the system is installed on three camera-seal systems. Until there is considerable positive experience of cooperation with the DPRK, however, the system should not be used as a reason to reduce actual visual inspections by trained inspectors.

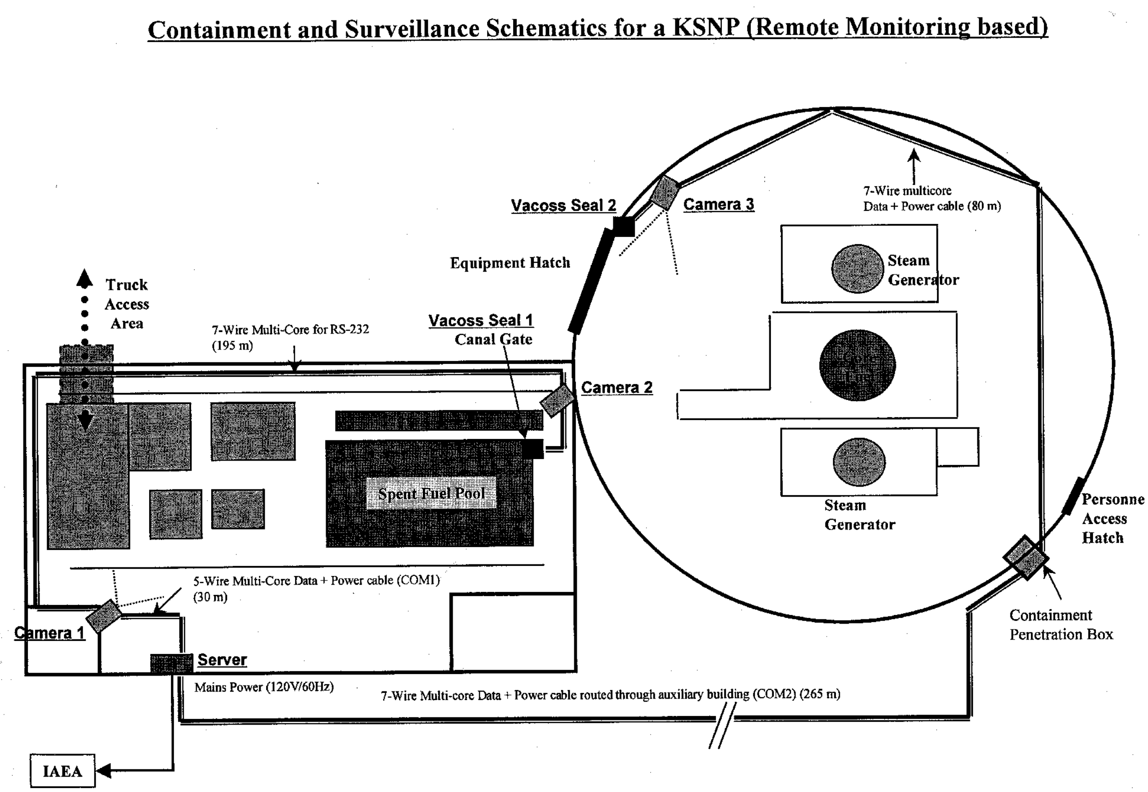


Figure 4-11. Advanced camera-seal system implemented in ROK reactors.

4.5.5 Safeguards Inspections During Routine Plant Operation

The safeguards accounting process and the verification of the integrity of the containment measures and surveillance devices are carried out by the IAEA safeguards inspectors during the plant inspections. The purpose of the inspections is to confirm the operators' recorded inventory of nuclear materials and to reconcile the records with the IAEA independent measurements. Each inspection is conducted by MBAs and is considered valid for a specified Material Balance Period. Two types of Inventory Verification inspections are carried out:

- Physical Inventory Verification (PIV). This inspection coincides with the physical inventory taken by the operator, most importantly during refueling outages. The detailed fuel accounting possible during such inspections allows the closing of the Material Balance Period.
- Interim Inventory Verification (IIV). This type inspection is carried out in periods in between two PIVs. Its purpose is to verify the status of CF and SF materials within the plant for meeting the timeliness component of the safeguards goals. Alternatively, the IIV is used to re-establish the continuity of knowledge of the status of the nuclear-materials inventory following a safeguards breakdown episode, e.g., a failure of the surveillance system.

IIV inspections are carried out four times during a calendar year, with the maximum time between two consecutive inspections being no longer than three months and three weeks. The period between inspections is governed by the timeliness criterion for inspecting plutonium-bearing fuels (CF and SF), which is three months. Because the reactor pressure vessel is closed during an IIV and the plant is in routine operation, the scope of the inspection is limited to verifying the C&S measures and inspecting the spent fuel. CF inventory is verified by checking the integrity of the seal(s) and the surveillance camera in the reactor building. The SF inventory in the fuel building is verified by checking the status of the C&S measures in the fuel building, by item counting of SF assemblies in the spent-fuel storage pool, and by carrying out non-destructive examination of SF assemblies using Cherenkov radiation-viewing devices. Because refueling outages in KEDO-type PWRs occur nominally every 18 months, the period between two refueling outages will be covered (from a safeguards perspective) by one PIV inspection, one PIV equivalent inspection, and four IIVs.

4.5.6 Physical Inventory Verification Type of Safeguards Inspection

The most comprehensive type of a safeguards inspection is the PIV inspection. The PIV is carried out nominally once every calendar year to correspond to the timeliness criterion for LEU in the fresh fuel. The maximum allowed time between two consecutive PIVs should not exceed 14 months, except if the PIV schedule coincides with a refueling outage. PIVs are carried out at yearly intervals even for reactors operating on an 18 months' refueling cycle. The PIV is carried out based on the nuclear-materials inventory records provided by the reactor operator. The IAEA inspects the plant records, reconciles them with the country statement, conducts its own inventory of the fuel in the plant, and further reconciles its own measurements with the plant records. If the IAEA can close the MBAs within the plant, and the total plant balance, the Material Balance Period can be closed.

Two types of PIV are carried out, depending on the plant's refueling outage schedule: a PIV during a routine plant operation with a closed core (called a PIV-equivalent inspection) and a PIV during a refueling outage. A PIV-equivalent inspection is similar to an IIV, except that for completion of the material balances the FF inventory is also determined. The fresh fuel on hand is a part of the FF inventory buildup toward the next refueling outage. The inspection activity for the FF assemblies includes items counting, serial number identification of individual assemblies and comparison with the plant records, and non-destructive assay (NDA). The inspection activity for CF is similar to the one carried out during an IIV and includes replacing the seals on the equipment hatch and on the transfer canal bridge gate, and inspecting the operating status of the surveillance camera in the reactor hall. The inspection activity for the SF is identical to that carried out during an IIV. It includes verifying the status of the C&S measures installed in the fuel building, item counting of the SF assemblies in the pool, and NDA inspection of the SF assemblies using Cherenkov radiation-viewing devices.

The most complex type of PIV occurs during a refueling operation, when the IAEA inspectors have to coordinate their inspection activities with the refueling work of the plant operators and with the physical inventory undertaken by the operators for completion of the plant's own records. The IAEA activities when a PIV coincides with a refueling outage can be divided into three distinct phases. Prior to the outage, the IAEA carries out Pre-PIV activities, which include removing the seals from the equipment hatch, the fuel transfer canal gate, and the top of the reactor core (if applicable), installation of a third, temporary, camera in the reactor hall facing the pressure vessel, and inventorying the fresh fuel in the fresh fuel pool prior to insertion into the reactor. At the end of the core refueling and before the closing of the pressure vessel, the IAEA conducts its own independent inspection of the fuel in the core. For the fresh fuel (both in the core and remaining in the FF pool), this includes item counting of assemblies, identification of individual assembly serial numbers, and NDA. For the core fuel, this includes item counting of assemblies in the core, serial number identification of FF assemblies in the core, and inspection of the permanent surveillance camera in the reactor hall. For the spent fuel, this includes assembly item counting and inspection of the surveillance equipment in the fuel building.

After the pressure vessel has been closed, the IAEA conducts Post-PIV activities. These include placing new seals on the equipment hatch, the spent-fuel transfer canal gate, and the vessel head assembly bridge; removing the temporary camera from the rector hall; re-inspecting the spent-fuel storage pools including SF assemblies item counting; inspecting all irradiated assemblies or parts of assemblies using Cherenkov and gamma-ray detectors; and verifying the status of the C&S equipment in the fuel building. At the end of these inspection activities, the IAEA compares its own inventory records with the plant operators' records and reconciles the differences.

4.6 Assessment of Additional Measurements and Inspections

The package of safeguards described in Section 4.5 has been adequate to prevent any covert diversion from safeguarded power reactors to date. The international community has not yet encountered a premeditated NPT breakout attempt by a determined and a resourceful country relying on the nuclear materials accumulated in a LWR plant. As discussed in Chapter 2, the currently applicable IAEA safeguards agreement with the DPRK (that follows INFCIRC 153) allows for additional measurements and inspections beyond the measurements and inspections at the reactors that have just been described. In this section, we discuss these additional measurements and inspections briefly together with their utility.

4.6.1 Measures for Strengthened Safeguards Under INFCIRC 153: Environmental Sampling

Under INFCIRC 153, the IAEA can carry out environmental sampling in the vicinity of declared sites but not at undeclared places without getting permission or requesting a "special inspection." The utility and practicality of environmental sampling in and around nuclear facilities have been validated through the conduct of field trials at the invitation of a number of member states. Samples can be collected from water, air, soil, and vegetation. Each has its own features. Water sampling has been shown to be an effective and relatively low-cost technique for both short- and long-range detection of nuclear activities, but a clandestine facility can prevent water-borne effluents from reaching the sampled bodies of water. Air sampling techniques can be applied to both airborne gases, such as ^{85}Kr, and airborne radionuclides associated with particulates, such as ^{129}I and ^{106}Ru. Some radioisotopes can only be detected locally, some as far as 100 kilometers from the site of emission. In some cases, highly sensitive modern analytic capabilities are needed, e.g., for sampling of emitted particulates. Signatures in soil and vegetation generally cannot be detected at ranges greater than approximately 10 kilometers and would be useful in the neighborhood of declared, and, in a special inspection, suspect facilities. While environmental sampling cannot provide 100 percent certainty of detecting covert or illegal activities, it faces a prospective diverter with a significant chance of detection, particularly if diverted material is not simply transported and stored, but is involved in some industrial process. The latter would have to take place if spent fuel is to be reprocessed to yield its plutonium.

4.6.2 Measures for Strengthened Safeguards Under INFCIRC 153: Remote Monitoring

As discussed in Section 4.5.4, field trials of remote monitoring of camera-seal systems are being successfully completed, though this measure has not been routinely implemented in safeguard systems. In addition to the camera-seal system, other sensors can also be remotely monitored:

(1) Portal monitors, video, and TESA-type locks[10] that record entry and exit information (personnel, date, time), and monitor nominal reactor operations, the movement (or non-movement) of nuclear material, and detect interference with containment or tampering with IAEA safeguards devices, samples or data.
(2) Reactor-emission sensors to provide facility data from operating reactors.
(3) Tamper-resistant electrical power monitors that would continually monitor and transmit to remote locations the current and voltage in an electrical transmission line, electrical substation, or power line entering and leaving the facility.
(4) Neutron spectrum and fluence monitors to indicate reactor performance between inspections.

This additional monitoring has yet to be tested. For several of the sensors, new procedures and transportable instrumentation must be developed.

Monitoring systems require reliable and sure means of data transmission to the analyzing organization. The DPRK (or power reactor vendors) will also probably require secure data transmissions. Actually three separate requirements (reliability, surety and security) can be provided by e commerce-type communications technologies.[11]

Reliability of the data provides for recoverable data in the case of communication errors, potential partial signal jamming, possible component failure, and power system vagaries. Surety is the portion of the data system that encapsulates the signal and meta data (timestamps, identification, and status records) to ensure an unambiguous data source and accuracy of attached meta data. Security is communication and data encapsulation that ensures that the message contents are not usefully disclosed to a third party. Reliability is provided by redundancy, error correction and backup components, and systems. Surety is provided by authenticated timestamps, digital signatures, and checksums. Security is provided by encryption, tamper-detection systems and secure communications channels.

Another necessary feature of any unattended monitoring system is automated review and analysis of acquired data. The classic method for sensing data review is the review of video monitoring data at video review stations after the fact. Typically, the surveillance tapes will be collected from the sealed monitoring units by inspectors and returned to a “home” facility for review. The tapes contain time-lapse images of the items being monitored. Existing video review stations allow the review of imagery at increased speeds. Yet, even with time compression of the monitoring system and review speed, each hour of human review time can currently only evaluate a little over a day of surveillance data from a single sensor. This makes clear the very labor-intensive nature of current video review efforts. An automated assessment tool for the video or other signal data streams that detect and assess changes and conditions indicating safeguards significant events is needed. Otherwise it may be weeks or months before information is reviewed. In certain cases, this may be too late.

4.6.3 Measures for Strengthened Safeguards Under INFCIRC 153: Other Recommended Steps

Other recommended safeguard measures include:

1. A Safeguards Center, a dedicated room for safeguards equipment and activities, is a recommended security consideration.
2. A redundant stable, uninterruptible power supply. Protection is needed against loss of power for safeguards equipment.
3. Adequate training for the DPRK situation, including red-teaming the particular physical and operational circumstances.
4. Updating equipment and training on a regular basis.

Safeguards, no matter how well designed, are only as good as the training, maintenance, and support systems that implement them. Given the DPRK's record of limited cooperation, inspectors will need to be trained to look beyond the conventional monitoring and inspection points for unexpected activities. All of these recommended steps necessitate that the IAEA and its member states pay special attention to the funding needs for safeguarding the KEDO reactors.

In conclusion, the additional measures and inspections described would clearly lower the probability of covert diversion from a safeguarded reactor. Absent any instance of such covert diversion from a safeguarded reactor, it is not possible to make this conclusion quantitative. Red-teaming could bring out some covert diversion possibilities that these additional measures and inspections would prevent. A systems approach to the overall package of safeguards must be taken to ensure that the particular additional measures taken are those that will add the most assurance for the money invested. The authors of this report have not had either the time or the specific data needed to carry out such an approach, which is rather the province of the IAEA.

4.6.4 Satellite Remote Sensing

Satellite-based remote sensing is not a part of the IAEA safeguards package, but if carried out by the U.S. or other member state, is a useful addition to safeguards. Satellite-based remote sensing may prove particularly applicable to detecting an "intent-to-abrogate" from requirements of the NPT treaty and IAEA agreements.

Reliable and informative remote sensing suffers from a number of difficulties. The weather does not always cooperate, the observed party may conceal facilities, equipment, and evidence from overhead view, and current commercial technology (and marketability) limits GSD (Ground Sample Distance) to a minimum of one meter, so that only items the size of automobiles or larger can be clearly distinguished.[12] Nevertheless, remote sensing can be the only source of timely information when trying to monitor broad areas, restricted facilities, or suspect sites in an uncooperative state. In particular, the following can be done.

<u>What can be monitored?</u> High-resolution imaging systems can monitor specific items and changes at a nuclear site. Synthetic aperture radar (SAR) can evaluate conducting items

(fences, transmission lines, pipelines, railways, equipment, and some industrial structures).

Shipping casks. Individual fuel shipping casks are large enough to be imaged from space, but the casks would need identifying marks to track from satellites. The state of a cask's contents cannot be determined from space, but if infrared imagery can determine the surface temperature of a shipping cask, it might be possible to infer something about spent fuel contents. Satellite imagery could also be used to count casks at a dry storage facility.

Cooling units, associated pumps, exchangers. The thermal state of elements of an industrial site can be evaluated by infrared imagery. The thermal output of a reactor can be estimated from temperature changes in exposed cooling water flows and cooling structures. The operational status of site facilities can be evaluated by monitoring the temperature of exposed heat exchangers, steam pipes, HVAC equipment, power transmission components, and gas exhaust plumes.

Facility construction at declared facilities. High-resolution imagery of sites clearly identifies outdoor changes associated with construction. Earthmoving, grading, plowing, disturbances from heavy vehicle traffic, building construction, and security perimeters are typically easily distinguished in satellite imagery. Change-detection techniques allow analysts to focus quickly on changes in sites between images acquired on different dates thus highlighting the effects of construction changes. Determining the nature of the construction and purpose of facilities is more difficult, but satellite imagery can be used to direct planning for and conducting of ground-based inspections.

What is the response time scale of satellite remote sensing systems?
The time scale for monitoring by satellite is determined by the orbital dynamics of the resources used and the local conditions at the site to be monitored. In the case of SAR, weather conditions are not important. Commercial satellites in polar orbits revisit exact positions in 15-26 day cycles. More frequent imaging of locations can be performed by systems with the capability to acquire images at angles other than perpendicular to the earth's surface. This additional capability allows images of a site to be acquired as frequently as once every 3-4 days.

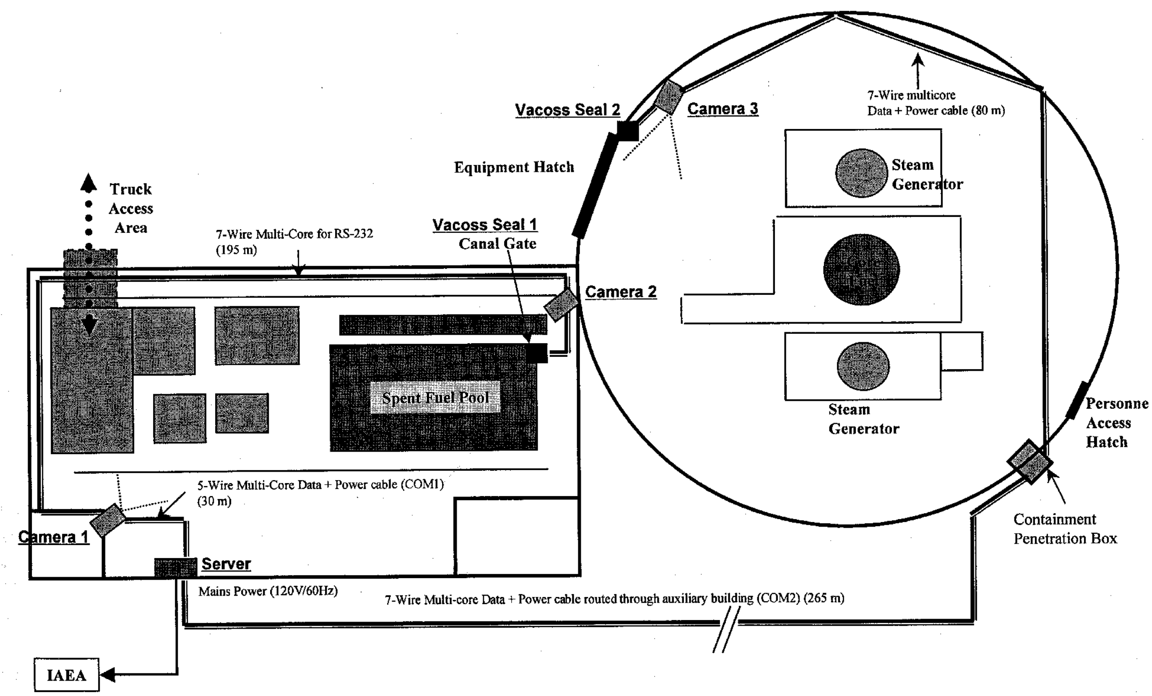
Remote-sensing resources. Table 4-1 lists some commercial, space-based remote-sensing platforms.[13] A number of additional imaging systems are planned for deployment in the next decade. The yet-to-be-deployed systems will generally not add significantly new technical capabilities in the near-term. Additional systems will provide greater revisit frequency, and perhaps an independence of imagery supply dependence on a particular country or corporate supplier and redundancy. Hyper-spectral imagery at high spatial resolution, not yet developed, might identify specific chemical species on surfaces and in gas and liquid plumes. This development might provide significant new monitoring capabilities.

Table 4-1. Commercial remote-sensing platforms.

System	Nominal resolution (m)	Revisit frequency (days)
IKONOS	1	14
SPOT	10	4
IRS	5	5
LANDSAT	15	?

Figure 4-11 (below) shows how the various additional monitoring measures considered in this section could augment existing safeguards activities at the KEDO reactors.

Containment and Surveillance Schematics for a KSNP (Remote Monitoring based)



4.7 Conclusions

As the foregoing discussion indicates, the IAEA safeguards under the applicable agreements—if carried out with adequate funding, cooperation of the host country, and preferably with augmentation from national technical means—provide high assurance that no nuclear-materials diversion has taken place as of the last inspection. Indeed, the global record to date suggests that no fuel diversion from a civilian LWR under safeguards has taken place. Both the quantity and the timeliness criteria on which the entire accounting and inspection system is based have proven adequate so far. Including the additional measures permitted under the applicable agreements and discussed above, safeguards in our opinion will give high assurance that *covert* programs at or near any inspected locale are not going on.

The international community has not yet encountered an *overt* premeditated NPT breakout by a determined and a resourceful country relying on the nuclear materials accumulated in a LWR plant. That option cannot be completely be ruled out but only protected against. In such a case, IAEA safeguards—supplemented by others indications of diversion discussed in the next chapter—should provide timely warning, which is to say, warning time shorter than the time required from diversion through fissile material refining to the manufacturing of a completed nuclear-explosive device.

Chapter 4 Notes

1. Korea Electric Power Corporation, Korean Standard Nuclear Power Plant (KSNP), Seoul, Korea, 1996.

2. Byung Ryung Lee, Keun Sun Chang, and Jun Seok Yang, Korea Atomic Energy Research Institute, *Korean Standard Nuclear Plants: Safer, Simpler, and Easier to Build*, Nuclear Engineering International, pp. 29-35, August 1992.

3. Korea Heavy Industries & Construction Co. Ltd. (Hanjung), Nuclear Power Plant, Seoul, Korea, October 2000.

4. The values cited in this paragraph, as well as the figure in the previous sidebar, were developed from a variety of data from different LWR reactor designs, using various initial enrichments, design burnups and operating cycles. They are intended for illustration only, and are not representative of any particular reactor or operating scenario.

5. Yousry Abushady, International Atomic Energy Agency, "Inspection Activities at Light Water Reactors," Paper Presented at the 2000 Workshop on IAEA Safeguards, NTC/KAERI, Taejon, Republic of Korea, August 9, 2000.

6. Byung-Koo Kim, Korea Atomic Energy Research Institute, "KEDO LWR Project for International Cooperation and Non-Proliferation," Paper presented at the Monterey Institute of International Studies, Monterey, California, July 24, 2000.

7. Neil Harms and Perpetua Rodriguez, International Atomic Energy Agency, Safeguards at Light Water Reactors: Current Practices, Future Directions," IAEA Bulletin 38/4, pp. 1-6, Vienna, Austria, September 29, 2000.

8. O.J. Heinonen, International Atomic Energy Agency, "Additional Protocol and Safeguards Agreements—The New Non-Proliferation Standard," Paper presented at the 12th Pacific Basin Nuclear Conference, Seoul, Republic of Korea, October 30, 2000

9. Daniel A. Pinkston, Center for Nonproliferation Studies, Monterey Institute of International Studies, "Implementing the Agreed Framework and Potential Obstacles," Paper presented at the 12th Pacific Basin Nuclear Conference, Seoul, Republic of Korea, October 30, 2000.

10. TESA Entry Systems, P.O. Box 620138, Atlanta, GA 30362-2138.

11. D.R. Manatt, R.B. Melton, C.E. Smith, and S.M. Deland, *International Safeguards Data Authentication*, Lawrence Livermore National Laboratory, Paper presented at the 37th Annual International Nuclear Materials Management meeting, Naples, Florida, July 28-August 1, 1996, UCRL-JC-124825.

12. High-contrast items smaller than the GSM limit can be imaged, but they cannot be unambiguously identified.

13. LANDSAT is a U.S. government system, but the images are available commercially.

CHAPTER 5
Diversion and Misuse Scenarios for Light-Water Reactors

5.1 Scope and Intent

This chapter briefly describes a few scenarios by which an LWR could conceivably be exploited for the purposes of:

1. diverting spent fuel to support weapons acquisitions, or
2. misusing the reactor to improve the quality of plutonium found in spent fuel.

Exploitation of an LWR for proliferant purposes requires bypassing safeguards, either covertly or overtly (by abrogating treaty obligations). Access to the reactor and to the spent fuel produced as a result of reactor operations is largely limited to the operations involved in refueling the reactor. This chapter also looks briefly at the major signatures and other indicators that might be observed and serve as early warnings of potential proliferant activities. We also look at some of the technical options that could reduce the consequences of diversion or misuse and those that can improve the reliability and / or decrease response time of safeguards measures.

There are scenarios by which an LWR power plant can "indirectly support" development of nuclear weapons. For example, LWR construction and operation can provide justification for the development of an underlying infrastructure and serve as a cover for a nuclear-weapons program. Some technologies associated with LWR operations, such as core physics computer codes, could be used for calculating weapons-materials production, either in the LWR or in other types of reactors (assuming the cross-section libraries for other types of reactors are available). However, such indirect scenarios are not discussed here.

Plutonium and Weapons

While all plutonium isotopes can be used in a weapon, not all isotopes are equally desirable. So-called "weapons-grade" plutonium has 90% (or more) of the isotope ^{239}Pu, and corresponding little of the other isotopes. All the "even" isotopes cause problems because they emit neutrons, which can lead to premature detonation and impaired reliability. The isotope ^{240}Pu is the most common of these. ^{238}Pu is also problematic, because it produces a great amount of heat in addition to neutrons. Even the "odd" isotope, ^{241}Pu, is somewhat less desirable than ^{239}Pu because of its higher neutron and heat production rates. Because all these other isotopes of plutonium are less desirable than ^{239}Pu, we can approximate the weapons-usable "quality" of reactor plutonium to be indicated by the concentration of ^{239}Pu.

5.2 Scenarios

The most important vulnerabilities associated with LWR nuclear-power plants are associated with plutonium: either that generated normally during reactor operations and bound up in spent fuel, or that potentially generated as the result of improper use of the reactor. Because plutonium is created in the LWR fuel as it is being used, the major proliferation concern is the diversion of spent fuel. As already noted, although the plutonium present in spent LWR fuel (so-called "reactor-grade" plutonium) is not ideal for nuclear-weapons applications, it is considered usable, and thus is an attractive target for theft or diversion of spent fuel resulting from normal reactor operations. Vulnerabilities associated with fresh fuel are minimal, as fresh LEU fuel has no value to a potential proliferator unless that proliferator has the facilities and capabilities for further enriching uranium. Other vulnerabilities associated with LWR plants are also relatively limited. Misuse of ancillary capabilities (such as gloveboxes) or application of skills, knowledge, and expertise to a weapons-development program offer little of value to potential proliferator, and are capabilities relatively easy to obtain.

The fact that spent LWR fuel is not ideal for weapons applications leads to the second concern: the intentional misuse of the reactor for producing plutonium with improved isotopic composition. Two scenarios are offered that could be used by proliferators to covertly produce such plutonium. A proliferator could substitute so-called "target" assemblies (assemblies specially designed to produce plutonium) in place of normal fuel assemblies, or could arrange to have some fuel removed prematurely from the reactor by making it appear to be "failed fuel." A common feature of these scenarios is that the material to be diverted in either case ends up in the spent-fuel pool. Thus, both of these scenarios share many features.

The last two scenarios discussed will be the overt misuse of the reactor to produce "weapons-grade" plutonium, either through "short cycling" the reactor or through modifications to the reactor core design. While these two scenarios could be attempted covertly, the complexity and signatures associated with these scenarios are of sufficient magnitude that detection is essentially assured and abrogation of the DPRK's international commitments would be required. We also briefly discuss the other options that the DPRK may have should it choose to abrogate its obligations.

5.2.1 Scenario: Covert Diversion of Spent Fuel Produced During Normal Reactor Operations

Diversion of spent fuel requires overcoming three obstacles: safeguards, radiation, and heat.

First, to covertly divert significant quantities of spent fuel successfully, the safeguards surveillance systems monitoring the spent-fuel storage pool and access portals have to be compromised. Current IAEA safeguards are specifically tailored to address this issue, and R&D continues on ways to improve the reliability of spent-fuel surveillance methods.

Second, even the least radioactive spent fuel requires transport in a heavily shielded container, and the activities associated with removing spent fuel from storage, and preparing and loading it into the transport casks require sufficient manpower that much of the operating staff would have to be involved with the operation.

Third, "young" spent fuel (spent fuel discharged less than several years) produces a great amount of heat and must be cooled to prevent damage or even melting (especially of very young spent fuel.)

The combination of these latter two obstacles places tough requirements on the design of the shipping cask. Shortcuts in the handling and transport of young spent fuel greatly increases the risk of fuel damage and poses significant personnel hazards.

Both the radiation and heat produced by spent fuel decays slowly with time, so older spent fuel can be considered to represent a greater diversion risk than fresher spent fuel. Because the oldest spent fuel (the BOL spent fuel) is also the spent fuel with the highest quality plutonium, this tendency is reinforced, and there is a desire (from a nonproliferation view) to preferentially relocated the oldest spent fuel and place it under more effective international control.

Spent-fuel storage pools do not normally have enough capacity to store all the spent fuel discharged during the life of a plant. As spent fuel ages, and the heat and radiation generated by the spent fuel lessen, the spent fuel can safely be stored in dry casks at the reactor site. These casks are very large, bulky, and difficult to transport without specialized equipment. Removing fuel from the casks is a difficult procedure owing to the high radiation field. The casks have tamper-proof seals to detect any attempt to open the casks. Safeguards of dry-cask storage areas rely on surveillance monitoring and on periodic inspections of inventory and cask-seal integrity. The size of the casks makes them detectable from satellites, providing additional surveillance certainty. Thus, diversion attempts on dry-cask storage areas incur difficulties similar to diversion attempts from spent-fuel storage pools, but could also be detected from surveillance satellites.

Diversion of spent fuel has a number of signatures, especially in a once-through fuel cycle. First, the movement of the spent fuel itself is observed via the installed safeguards measures. Cameras and portal seals verify the security of access, and advanced notice of spent-fuel storage facility activities involving the movement of spent fuel is normally required. Related signatures include evidence of intrusion or illicit activities detected directly by the monitoring equipment and evidence of manipulation of the monitoring equipment (perhaps observed as failures in the monitoring equipment). Raising spent fuel from the storage pool increases the radiation level in the facility and is readily detectable.

Because diversion of spent fuel requires transport of the material away from the reactor site, a transport cask is needed. Even a cask designed to bare minimum requirements will be large and bulky, and likely observed from surveillance satellites, although the cask may be on site for a relatively short time (on the order of hours.)

In order for spent-fuel diversion to remain undetected, the diverted spent fuel must be replaced with a dummy that mimics the appearance and characteristics of the diverted fuel assemblies. Safeguards practices include periodic surveys of spent fuel to verify both the appearance and the nuclear characteristics of the material. A dummy fuel assembly with such characteristics presents similar radiation hazards to normal spent fuel. This in turn requires remote handling during the manufacture, necessitating potentially observed facilities. Transport requires a similar (or same) shipping cask as normal spent fuel. Movement of the dummy assembly into the spent-fuel storage area would entail the same observables as moving the real spent fuel out.

5.2.2 Scenario: Covert Materials Production

The ability to covertly misuse an LWR to produce better quality plutonium than that found in normal spent fuel is limited. It is technically feasible to introduce a small number of target assemblies specially designed to improve the production of weapons-quality plutonium. However, the physics of the LWR core makes it essential that such target assemblies remain in the rector for very short periods of time. While such target assemblies could be designed to partially overcome this obstacle, it is unlikely that a target assembly could produce high-quality plutonium if left in the core for the entire 4.5-year life of a normal fuel assembly. Thus, any attempt to misuse an LWR for materials production is likely to require that some fuel be removed from the reactor well before the normal fuel lifetime.

During refueling, LWR operators inspect fuel assemblies before reinserting them back into the core, with more careful inspections if there have been indications that some fuel damage has occurred. It is feasible that a potential proliferator could arrange to have some fuel or target assemblies modified to appear defective as a justification for removing them at relatively low burnups.

The possibility of defective fuel presents additional safeguards implications. Any fuel (either failed or not) removed before achieving nominal burnup will have a plutonium isotopic composition similar to BOL fuel, and thus represent a more attractive diversion target. Thus, there is some incentive for verifying that only truly failed fuel is removed prematurely from the reactor. The fuel designed for these reactors is expected to be "reconstituted," that is, in the event of fuel failures, individual fuel pins can be replaced and the bundle reinserted into the reactor. On the one hand, this increases the number of accountable items because individual fuel pins become accountable. On the other hand, it reduces the accumulation of low-burnup spent fuel because only those failed fuel pins remain in the spent-fuel storage pool.

Such a scenario requires several steps. First, an expectation of failed fuel needs to be established to prepare the inspector to accept the unusual fuel change-out. This requires spoofing the reactor failed-fuel monitoring equipment. Such an expectation also serves to mask the true intent of the misidentification of the failed fuel. Alternately, a fresh fuel element might be covertly "pre-damaged" prior to initial insertion into the reactor so that it would be a truly "failed" fuel element at the next refueling. Because fresh fuel is to be imported into the DPRK, pre-damaging it would require cooperation from the country of origin, presumably the ROK, or the fuel would have to be covertly damaged at the plant site.

Second, the "failed" fuel would have to be "identified," likely through spoofing of fuel inspection procedures or by contaminating (or otherwise camouflaging) the fuel to appear failed.

Third, the evidence of failed fuel would have to be sufficient to convince the on-site refueling inspector.

From there, the "failed" fuel would be placed in the spent-fuel storage pool. Generally, failed or suspect fuel is first placed in a specialized storage cask (or sleeve) to isolate the failed fuel and minimize potential for contaminating the spent-fuel storage pool. Once in the storage pool, the fuel is no more or less vulnerable to diversion than any other spent fuel, with the slight possible complication of (perhaps) needing to remove the fuel assemblies from the failed-fuel storage cask.

An advantage (to the proliferator) of this scenario is that it provides a mechanism for producing spent fuel of higher plutonium quality within the normal operating procedures of the reactor. Conversely, the use of reconstituted fuel assemblies significantly reduces the amount of low-burnup spent fuel that could be accumulated under such a scenario.

Such a scenario has several observables. First, utilization of special target assemblies to optimize plutonium production requires obtaining such assemblies and introducing them into the normal fuel supply. Arranging for fuel assemblies to fail (or to appear failed) requires similar efforts. Accomplishing such a feat requires fooling of safeguards, either by falsifying records and/or swapping target assemblies for real fuel assemblies, as well as avoiding detection during fuel handling and fuel inspection. Safeguards practices are specifically designed to detect the introduction of extraneous fuel assemblies into the fuel supply.

The second observable occurs in the need to manufacture the target assemblies, which would require the acquisition of a number of items and materials subject to various export and nuclear supplier restrictions. The target assemblies have to be indistinguishable from the real fuel assemblies, have the serial numbers of the real fuel assemblies, and the real fuel assemblies being replaced have to be covertly removed from the site.

The third observable in the scenario requires some justification for removing the special assemblies before the end of the normal fuel life, most likely after a single cycle.

Finally, even if such assemblies are successfully irradiated, they end up in the spent-fuel storage pool and must be covertly removed.

5.2.3 Scenario: "Short-Cycling" the Reactor

A reactor can be operated for less than its normal cycle, reducing burnup and improving the quality of the plutonium in the spent fuel. This "short-cycling" can be either covert or overt. Covert short-cycling of the reactor is limited to premature discharge of only a few fuel assemblies, perhaps as "failed fuel" as discussed above. Premature discharge of more than one or two such assemblies is so unusual that detection is essentially certain and the scenario must be considered overt. There are few "legitimate" reasons for short-cycling a reactor, and these are generally for safety-related issues such as component failure (including severely failed fuel), system leaks, and control problems. Most safety- and control-related reactor shutdowns do not necessitate opening the reactor, let alone handling fuel.

Thus, if potential proliferators wanted to short-cycle a reactor to covertly produce plutonium of higher quality, they need to concoct a relatively elaborate scheme to make the early shutdown appear justifiable, especially one which requires even partial unloading of the reactor core. Even if such a covert scenario were followed, it would likely be limited to the diversion of very few fuel assemblies, owing in part to the necessity to have replacement fresh fuel available. Normally, a reactor operator maintains a small stock of fresh fuel in the event that a fuel element requires replacement, but fuel is relatively reliable, and the necessary stock of surplus fuel is small.

In addition, once the "short-cycle" fuel was removed from the reactor, it would eventually have to be diverted from the spent-fuel storage pool, as in Scenario 1.

Short-cycling a reactor creates a number of observable signatures related to the loss of power. First is the loss of power to the grid that may be detected if the power grid has "external" connections (especially if significant power is normally exported, or is monitored. Second is the loss of "dump heat"[1] that can be remotely detected by the loss of infrared signals. Both signatures should be detected promptly, and certainly within the time needed to cool the reactor prior to removing the head and gaining access to the fuel (which normally takes a few days).

Diverted short-cycle spent fuel must be replaced if the reactor is to remain operating. Thus, replacement fresh fuel has to be obtained (probably in advance of the reactor shutdown) and this has to occur many months sooner than for normal reactor operations. The early accumulation of fresh fuel would thus indicate possible reactor short-cycling.

In the event of overt short-cycling of the reactor with a goal to obtain plutonium with 90% ^{239}Pu, burnup would be limited to no more than about 7 MWd/kg, limiting the reactor cycle time to approximately 9 months. Assuming an industry average of 40 days per refueling outage and refueling of the entire core, the reactor could produce as much as 150 kilograms of plutonium (containing approximately 90% ^{239}Pu) every 10 months.[2]

If the goal was to obtain a limited quantity of 90% ^{239}Pu with a minimum of observables, then the reactor could simply be shut down within about 9 months of the last refueling. At equilibrium, 1/3 of the core (the last fresh fuel reload) would contain approximately

50 kilograms of plutonium with about 90% ^{239}Pu. In such a case, the primary observable would be the premature shutdown of the reactor.

We note again that the previous two paragraphs apply to overt diversion, in which case the DPRK abrogates the AF and withdraws effectively from the NPT.

5.2.4 Scenario: Overt Reconfiguration of the Reactor for Materials Production

While LWRs can be short-cycled to improve the isotopic composition of plutonium found in the spent fuel, such an approach is costly, both in terms of operating costs and lost revenues. Weapon-materials production through the use of special “target” assemblies, or through the ruse of “failed fuel,” offers very limited capabilities for materials production. To provide significant increases in materials’ quality and quantity requires the introduction of a large number of target assemblies. Target assemblies using depleted uranium, arranged as a blanket surrounding the core (a region of reduced neutron flux) would help extend the cycle time of the reactor, while helping to improve the quality of the plutonium produced. However, such an approach significantly reduces the total amount of reactivity in the core (a measure of how much “active” fuel is in the core), significantly affects the thermal and nuclear performance of the reactor, and dramatically impacts the performance of the reactor control systems. These effects lead to the need to substantially reconfigure the reactor core to achieve significant increases in the quantity and quality of discharged plutonium.

Such modifications are expensive and time-consuming and require significant reactor-design capabilities. Moreover, the modified reactor would require fuel substantially different from that normally used, probably requiring much higher enrichments than normal LWR fuel. Thus, besides the design and manufacturing efforts associated with the core reconfiguration, a source of fuel and enrichment capabilities also has to be provided.

The modifications necessary to achieve these goals could not go unnoticed under any inspection regime, and an overt abrogation of treaty responsibilities would appear necessary. While design and construction of the modifications might proceed before any overt display of intent, the lack of known enrichment capabilities in the DPRK means that an external source of fuel would be an essential element of such an approach.

In a “worst-case” scenario, one in which all modifications were compatible with the existing core internal structures and all materials (including both modified fuel assemblies and target assemblies) were available prior to modifying the reactor core, the substitution could not proceed without notice by inspectors. On the other hand, it may be feasible that the modifications could proceed in approximately the same time as required for a normal refueling (perhaps as little as 15 days, but more likely 30-60 days). This means that the rest of the world could expect at least 15 days to respond to an abrogation before reactor restart (and some additional time—on the order of several weeks—before significant plutonium could be accumulated.)

5.3 Consequences

The primary consequence of diverting spent fuel from an LWR is tied to the quality and quantity of the plutonium contained in the spent fuel. Normal reactor operations result in the discharge of nearly 300 kilograms of reactor-grade plutonium each 18 months, with lesser discharges of somewhat higher quality plutonium during the beginning of the reactor life. The spent fuel discharged during the beginning and end of reactor life, while still not considered “weapons-grade” would be somewhat less difficult to design and fabricate into a weapon than the higher burnup equilibrium fuel. Because all plutonium produced as a result of LWR operations is considered “weapons-usable,” these differences must be considered differences in degree, not differences in kind. An approximation of the projected accumulations of spent fuel is summarized in **Table 5-1** and **Figure 5-1**.

Table 5-1. Accumulation of LWR Plutonium in Spent Fuel.

Time from First Startup (Years)	Discharged Low-Burnup Pu (kg)	Discharged Medium-Burnup Pu (kg)	Discharged High-Burnup Pu (kg)	CumulatedTotal Pu (kg)
1.25	100	0	0	100
2.5		175	0	275
4			275	550
5.5			288	838
-				
40	100	175	288	7,737
Total Discharges	200	350	7,187	7,737

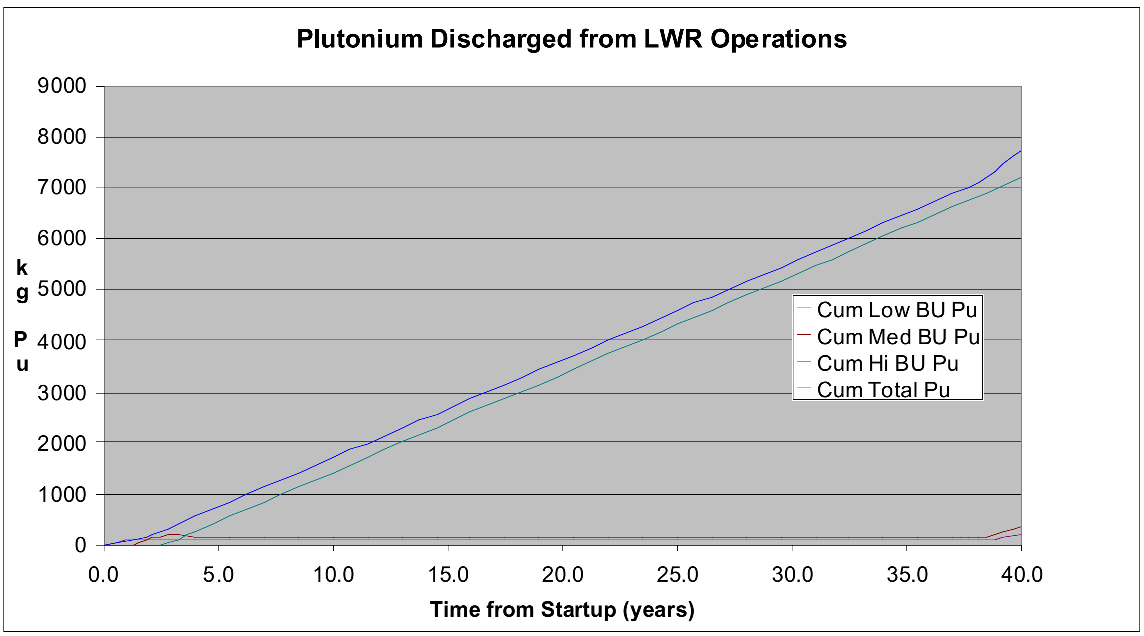


Figure 5-1. Plutonium discharged from LWR operations.

As already discussed, overt short-cycling of an LWR could produce as much as 150 kilograms of essentially "weapons-grade" plutonium roughly every 10 months, and there some potential that smaller amounts could be accumulated through some of the scenarios discussed here. Safeguards have been designed to help detect such activities and minimize the potential for such attempts. Thus, production of substantial quantities of low-burnup plutonium and subsequent diversion of it likely requires an overt abrogation of treaty obligations.

Exploitation of the plutonium produced in an LWR requires reprocessing to extract the plutonium. Although reprocessing of spent LWR fuel is similar to the reprocessing of spent fuel from graphite reactors (for which the DPRK has experience), there are some notable differences. First, LWR fuel is clad with zircalloy, a very durable alloy that complicates dissolution of the fuel (as compared with magnesium-clad metal fuel that is easily dissolved.) The LWR fuel must be mechanically chopped into small pieces, and the toughness of the alloy makes this a difficult process. Second, the complexity and size of the LWR fuel assembly (hundreds of very long pins as opposed to the single short slug of a graphite reactor fuel element) further complicates this process. Third, the combination of the zirconium and oxide fuel makes the chemical dissolution step itself slower than dissolution of the magnesium-clad metal fuel used in the graphite reactors. Finally, spent LWR fuel has higher radiation levels than graphite reactor fuels, due both to its higher burnup and the fact that the fuel assemblies themselves are much larger. In short, even if an active reprocessing capability for the graphite reactor fuel is available, a new front end to the reprocessing facility must be provided to prepare the spent fuel for reprocessing. This front-end needs to be co-located with and likely contiguous to the rest of the reprocessing facility, as the dissolved fuel is too radioactive to be reasonably shipped.

5.4 Preventive Measures

As just described, reducing the proliferation risk associated with potentially weapons-usable plutonium generated by reactor operations fall into several broad areas:

1. Reducing access to plutonium-containing materials,
2. Reducing the quantity or quality of the plutonium in spent fuel,
3. Reducing the desirability of misusing the LWR for weapon-materials production.

For practical purposes, all covert scenarios for misusing an LWR for weapon-materials acquisition can be reduced to the issue of spent fuel diversion. LWR power plants, by nature, are quite robust against misuse or modification for weapon-materials production. As has been discussed, such misuse is expensive, time-consuming, and involves sufficient observables that are easily detected. Because the DPRK reactors are copies of existing designs, there are few, if any, substantial modifications to the reactors or the plants that could significantly reduce the risk of misuse, a risk that appears relatively low to begin with. Remote monitoring of plant-operating characteristics, both directly (through telemetry of plant parameters) and indirectly (through remote surveillance), discussed in the previous chapter, is an area of technology that could improve the ability of the safeguards community to detect and reduce the attractiveness of any of the scenarios discussed.

Increasing the burnup capability of LWR fuel is the most promising near-term approach to enhancing the intrinsic proliferation resistance of the LWR fuel cycle, including those in the DPRK. In addition to reducing the quality and overall quantity of plutonium resulting from LWR operations, it can reduce overall fuel cycle costs and thus is an attractive option for the reactor operator, and could be implemented within the AF. Research is underway, both in the U.S. and abroad, to extend the burnup capability of LWR fuel, and this option could become available in time.

Other technologies have been proposed to further enhance the proliferation resistance of LWR plants and associated fuel cycles. Most, if not all, of these options fall far outside the bounds of current LWR practice and are likely unacceptable within the guidelines of the AF. One example is the addition of substances to fresh fuel to make fresh fuel radioactive as a deterrent to theft and diversion. Such an approach, while feasible, introduces complications that significantly increase the cost of the fuel, reduces safety, and complicates transport, inspection, and handling. Moreover, such an approach deals only with the proliferation risk of fresh LEU fuel, a risk already considered very low. As such, it is unlikely that such measures would be willingly accepted by any plant operator.

The issue of the higher-quality spent fuel resulting from BOL operations can be eliminated by initially fueling the reactor with partially irradiated fuel, such that all BOL spent fuel would be exposed to full design burnup on discharge. That approach introduces a number of technical and operational challenges and is outside the bounds of current reactor operations. Partially irradiated fuel rods are much more prone to damage during handling and transport than fresh fuel and introduce significant risks for fuel failures on re-irradiation. The operational challenges include, among others (1) identifying a source of the partially irradiated fuel, (2) licensing the partially irradiated fuel for use following the additional handling and transportation involved, and (3) ensuring personal protection and facility safety when introducing partially irradiated fuel into the reactor operations normally designed to handle fresh fuel. None of these steps are even remotely practical or economic.

In summary, the best practicable methods for preventing the diversion scenarios outlined are the ones described in Chapter 4, Section 4.6. These methods, under the conditions recommended, protect against covert scenarios so that other methods of attaining a weapon capability, other than covert diversion from the KEDO reactors, would probably be chosen by any proliferator. Overt diversion, the abrogation of agreements, cannot be prevented by safeguards, though they can be warned about and damage can be limited. This overt scenario is discussed in Chapter 8.

Chapter 5 Notes

1. Only about 1/3 of the power produced in the reactor is turned into electricity, the remaining 2/3 is wasted and dumped to the environment. The dumped-heat infrared signature of an operating reactor is easily detectable from satellites.

2. These data are obtained from the rough approximations of plutonium production in LWRs described earlier. Plutonium production rates vary broadly with fuel enrichment, and using lower fuel enrichments would likely reduce cost and optimize plutonium production. Significant additional analysis is required to determine more accurate estimates of fuel requirements and of material production and plutonium isotopic contents at these lower burnups.

3. The values for accumulated plutonium shown in Table 5-1 and Figure 5-1 refer to the plutonium content of freshly discharged spent fuel and do not account for the decay of plutonium, mostly associated with the decay of the short-lived isotope ^{241}Pu.

CHAPTER 6
Known and Suspected Nuclear-Related Facilities in the DPRK

6.1 Inspection, Dismantlement, and Disposal Requirements for Existing Nuclear Facilities

6.1.1 "Full-Compliance" Inspections by the IAEA

The AF provides that the DPRK must come into "full compliance with its safeguards agreement with the IAEA" when a "significant portion of the LWR project is completed, but before delivery of key nuclear components." This means completion, to a stage still to be agreed on, of the buildings for the turbine generators for the first LWR at Kumho and delivery of its turbine generator but not the LWR itself or key nuclear components for it. Thus, before IAEA inspection is required of facilities other than those "declared" to the IAEA by DPRK when DPRK accepted its safeguards agreement, KEDO must complete major construction of buildings at Kumho and deliver much of the non-nuclear equipment for electric generation. The specific stage of construction and delivery required is to be agreed in a "delivery protocol."

Believing that the inspections and analysis necessary to show "full compliance" will take two to three years, the IAEA has been pushing the DPRK to permit these inspections to begin even though completion of construction of the LWR buildings and delivery of the turbine generator are still a year or more ahead.

6.1.2 Disposal of Spent Fuel

When the transfer of key nuclear components to Kumho for the first LWR takes place, the DPRK is obligated by the AF to begin transfer of the spent fuel stored in the cooling pond near the small graphite reactor at Yongbyon. Transfer will presumably continue during the period of delivery and installation of key nuclear components for the second LWR at Kumho because the spent fuel is all to be transferred to "ultimate disposition" by the time that LWR is completed at Kumho. The AF does not specify where the spent fuel is to go but says that DPRK and the U.S. will "cooperate . . . to dispose of the fuel in a safe manner that does not involve reprocessing in the DPRK." Thus, where the spent fuel will go and how it will be transported there still remains to be decided.

6.1.3 Dismantlement of Gas-Graphite Reactors

When the first LWR is completed at Kumho, the dismantlement of the three existing gas-graphite reactors and "related facilities" at Yongbyon, Taechon, and elsewhere must begin. This dismantlement must be completed by the DPRK when the LWR project (including installation of the second LWR) is completed at Kumho. More agreement than this on how this dismantlement will be scheduled, including how it will be coordinated with steps toward installation of the second LWR at Kumho, remains to be negotiated. The technical problems do not appear to be major, but how the dismantlement will take place and where the dismantled parts of facilities will go remains to be decided.

6.2 The Facilities at Yongbyon

The main site for the North Korean nuclear program was the Yongbyon Nuclear Center, about 100 kilometers north of Pyongyang, on the Kuryong River (**Figure 6-1**). Many of the facilities at the site have been "frozen" as a result of the AF of 1994, but the site as a whole is still active.

Figure 6-1. Satellite Photo of the Yongbyon site, by Space Imaging Corporation, 2000. The facility extends on both sides of the river throughout essentially the entire photograph.

The site includes facilities for fuel manufacture, three nuclear reactors, at least one hot-cell facility, at least one spent-fuel reprocessing facility and several waste sites. There is also a high-explosives testing area, which has been inactive since at least 1992.[2]

The North Koreans reported to the IAEA that the site was dedicated to the pursuit of peaceful nuclear energy and there was no weapon program. However, inspections, measurements, and satellite photographs have shown suspicious activities. As of this writing, it has not been determined exactly which of the Yongbyon facilities were for weapons-manufacturing and which (if any) were for energy production. It is possible that entire site was a dedicated weapon facility that used a peaceful cover story. Given the activities observed, it is unlikely that the site was dedicated entirely to peaceful purposes.

Uranium mining, milling, and refining operations were carried out at other sites in North Korea. The DPRK has sufficient domestic uranium resources to be self-sufficient in that regard. The estimated capacity of North Korea's mining and milling operations in 1992 was 300 tonnes per year of uranium.[3] There are no known uranium isotopic-enrichment facilities in DPRK. The reactor program was to operate with fuels of natural enrichment, with the exception of the Soviet-supplied IRT-2000 research reactor.

In the rest of this section, we describe the main facilities, declared and suspected, at Yongbyon.

6.2.1 IRT-2000 Research Reactor

In 1965, the IRT-2000 reactor was commissioned in Yongbyon. The reactor is light-water-cooled and moderated, uses enriched uranium fuel, and was designed to operate at a power level of 2 MW(th) [later the power level was increased to 4 MW(th) and then 8 MW(th)]. Soviet nuclear reactor specialists departed the DPRK after the reactor was completed, but continued to cooperate on agreements to supply the enriched fuel.[4] The reactor was placed under IAEA safeguards in 1977.

6.2.2 Isotope Production Laboratory Near the IRT-2000 Reactor

In the northern part of Yongbyon, there is a set of laboratory buildings including one designated as the Isotope Production Laboratory. In this building, there are hot cells for handling radioactive material. This is where North Korea first produced plutonium, generated in uranium targets in the IRT-2000 reactor. They have admitted to the production of less than of gram of the material by this means.

6.2.3 Probable Undeclared Waste Site South of the IRT-2000 Reactor

Near the (uncompleted) 50-MW(e) graphite reactor is an undeclared waste site that was probably in operation from the 1970s until August 1992. From satellite imagery (**Figure 6-2**), it was determined that the undeclared waste site contains two cylindrical tanks, each about 5.8 meters in diameter, in addition to a rectangular arrangement. This type of waste site is commonly associated with IRT reactors. Iraq, for example, has an almost identical facility at the Tuwaitha Nuclear Research Center. It has two dry wells for storage of irradiated fuel elements, plus two cylindrical tanks for storage of liquid radioactive waste. The site at the Yongbyon facility was covered with dirt in August 1992, and the road leading to the site was hidden by freshly planted trees. Some of the trees then died within a few months, and more vegetation was planted. The IAEA has not been allowed access to the waste stored at this site, but it is suspected that waste from processing IRT reactor targets is stored there.

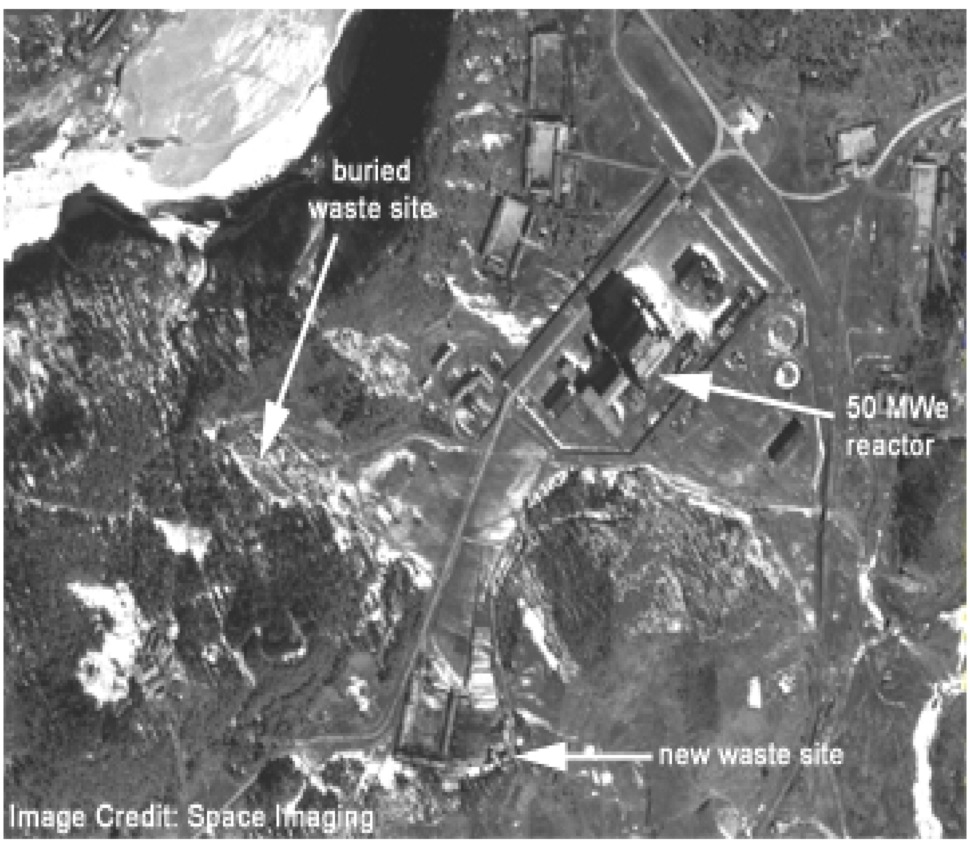


Figure 6-2. The buried and the new waste site near the (uncompleted) 50-MW(e) graphite reactor. Only the new waste site was declared and the IAEA has not yet been allowed to inspect the buried waste site.

6.2.4 Declared Waste Site

Nearby, there is a declared waste site that did not exist in until mid-1992. The North Koreans, nevertheless, stated that this site has been active since 1977, holding solid waste in 28 steel-lined storage pits (upgraded to 42 pits in 1990). The deliberate concealment of the older waste site, together with the false history of the declared site, make it appear that the IRT-2000 reactor produced significant amounts of plutonium, and that the wastes have been concealed.

6.2.5 5-MW(e), 20-MW(th) Graphite-Moderated Reactor

In the early 1980s, construction of a nominally 5-MW(e), 20-MW(th) graphite-moderated power reactor was started in Yongbyon. A decision to seek nuclear weapons could already have been made at this time, and the graphite-reactor technology would be easily adapted to a dual-use role. The reactor design appears to be based on the British Calder Hall reactor, which was originally built to produce electricity and support the British nuclear-weapons program (**Figure 6-3**). Calder Hall, the first of the so-called MAGNOX reactors, was commissioned in 1956. It is still operating.

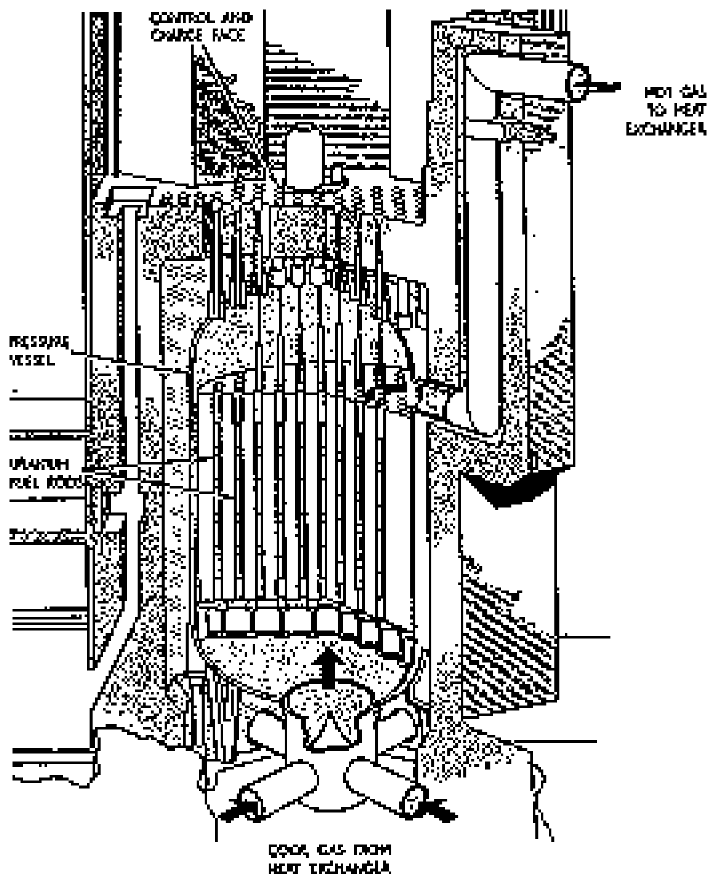


Figure 6-3. Schematic drawing of the core of the 60-MW(e) Calder Hall Reactor, which began operation in the United Kingdom in 1956. The 5-MW(e) graphite reactor in Yongbyon is based on the Calder Hall design.

The Yongbyon design uses uranium-alloy (99.5% U, 0.5% Al) fuel rods in magnesium-alloy (99.5% Mg, 0.5% Zr) tubes. The rods are 2.9 centimeters in diameter and 52 centimeters long and contain 6.24 kilograms of the uranium alloy. The tube walls are roughly a millimeter thick but there are longitudinal fins, bringing the outer diameter to about 5 centimeters. Cooling is by forced convection with carbon dioxide gas under 6 bar of pressure.

The reactor core consists of a set of large graphite blocks, with 812 vertical holes ("channels") bored in them for the fuel and coolant. The holes are 6.5 centimeters in diameter. There are10 fuel rods per channel, stacked vertically. The diameter of the core is 6.4 meters and the height, not including reflectors, is 6 meters. The maximum thermal power is probably 20 MW.

6.2.6 Fuel Reprocessing Facility

During the late 1980s, a fuel-reprocessing facility was constructed. The facility is housed in a building 192 meters long and six stories tall, which is quite visible in satellite photographs (see Figure 6-4). In 1994, the facility had a nominal capacity to reprocess 220-250 tonnes of MAGNOX spent fuel per year, using two PUREX[5] processing lines, if the lines are operated 24 hours per day, 300 days per year.[6]

Figure 6-4. Satellite photograph showing the plutonium separation building and associated buildings and the suspect waste building, the so called Building 500 where nuclear waste from undeclared reprocessing campaigns is suspected to be hidden. The waste could include 50 tons of uranium and 30 kilocuries of ^{137}Cs.

The spent fuel from the MAGNOX reactor would be transported to the south end of the reprocessing facility by truck in buckets within shielded casks. The buckets and fuel rods would then be moved to the north side of the building by remotely operated vehicle and the processing occurs in the southerly direction.

Along the eastern side of the building is a complex set of storage tanks within shielded vaults that contain liquid processing wastes of low- and intermediate-radiation levels. At the southeastern end of the building is a vault containing two storage tanks for highly radioactive fission-products. About 120 meters east of the reprocessing building is an L-shaped building associated with the storage of highly radioactive waste. There are four tanks just south of this building in an underground vault that contain most of the volume of the declared reprocessing high-level waste.[7]

6.2.7 Undeclared Waste Storage Building

An undeclared waste storage building (sometimes called Building 500) is located about 300 meters east of the main reprocessing building. This building, built primarily in 1991, is 18 meters high (including the basement), 24 meters wide, and 67 meters long. The basement has four large pits for liquid-waste storage tanks and six smaller compartments for storage of containerized solid wastes. The basement is covered with concrete slabs for shielding. Trenches were dug and piping was installed from the main reprocessing building in the winter of 1991-92. It is suspected that this piping was used for pumping aqueous radioactive wastes containing fission products and spent uranium from undeclared reprocessing campaigns in 1989-91. Inspectors who visited this building during the third, ad hoc inspection of September 1992 were told incorrectly that this building has no basement, and that it is a workshop for military vehicles.

6.2.8 Other Unfinished Reactors

Construction began on two other graphite reactors, one a nominally 50-MW(e) reactor at Yongbyon and another a 200-MW(e) reactor at Taechon. Neither of these two reactors was completed. It has been speculated that the 50-MW(e) reactor at Yongbyon was to have been the main producer of weapon materials (in conjunction with the reprocessing facility) and the Taechon reactor was to be for electrical production only.

6.3 Verification of Initial DPRK Declaration

IAEA inspections were meant to verify the correctness and completeness of the initial declaration of nuclear materials that the DPRK provided to the IAEA on May 4, 1992. The declaration includes statements as to:

1. The nuclear material inventory of seven facilities that has been declared by DPRK to the IAEA as subject to safeguards.
2. Design information of those seven facilities.
3. A list of locations of nuclear materials outside these facilities.
4. A list of nuclear facilities under construction or planned.
5. A list of scientific institutions.
6. A list of nuclear facilities related to the nuclear industry.

The first IAEA visit occurred on May 11-16,1992, and was followed by six ad hoc inspections to determine the correctness and completeness of the initial declaration. These inspections, and some meeting and correspondence dates associated with those inspections, are listed in **Table 6-1**. Attempts to inspect two undeclared facilities at the Yongbyon site in early 1993 under "special inspection" authority were blocked. DPRK then announced that it was withdrawing from the NPT. Although its withdrawal was suspended, the DPRK has never allowed special IAEA inspections. The IAEA began conducting routine inspections at the 5-MW(e), 20-MW(th) gas-graphite reactor and the other two unfinished graphite reactors and related nuclear facilities declared by DPRK starting shortly after the AF was signed.

Table 6-1. Visits and Inspections by the IAEA of North Korean Facilities (Albright, Appendix 4).

Dates	Purpose and accomplishments
May 11-16, 1992	Initial official visit by Director-General Hans Blix and delegation.
May 26-June 5, 1992	First ad hoc inspection to verify the initial declaration.
July 8-18, 1992	Sampling of radiochemical lab includes swipes in and around 5 glove boxes that compose the plutonium-production area of the lab.
September 11-14, 1992	Visits to radiochemical lab and fuel-fabrication complex. Acting on suggestions made by the U.S., there are visits to the high-explosive facility and to Building 500, which appears to be a single-story building under military control.
November 2-13, 1992	IAEA provides DPRK with details of the inconsistencies and requests an explanation. Answers are not satisfactory to IAEA, who has been shown U.S. satellite photos of the construction of Building 500 and the trenches leading to it.
December 22, 1992	Hans Blix requests extraction of samples around basement of building in question.
January 5, 1993	DPRK s Atomic Energy Minister Choi rejects Blix's request.
January 1993	Agency task force summarizes inconsistencies and makes recommendations for a set of measurements on reactor fuel.
January 20-22, 1993	El Baradei of IAEA visits Pyongyang to request special inspections of the two undeclared waste sites. Response is that the sites are military and non-nuclear there will be no inspections.
January 26-February 6, 1993	Sixth ad hoc inspection. Extensive meetings and discussions between IAEA team and DPRK officials discussing isotopic inconsistencies found in swipe samples from radiochemical lab.
February 22-23, 1993	IAEA Board of Governors meets and discusses findings of inconsistencies. Satellite photos are shown. Board decides to support Blix, and declares that inspection of additional sites is essential to ensure verification of compliance with the agreement.
March 12, 1993	DPRK announces its intention to withdraw from the NPT.
May 10-14, 1993	Seventh ad hoc inspection team visits Yongbyon and performs maintenance and replacement of safeguards equipment at reactor.
June 11, 1993	DPRK announces suspension of NPT withdrawal, based on negotiations with U.S. Assistant Secretary of State Gallucci.

The declaration claimed that the very first core-load of fuel was still in the 5 MWe graphite reactor and that only a few defective fuel rods had ever been removed. To the contrary, the evidence discussed below leads to the suspicion [mm] that beginning in 1989 large amounts of spent fuel from the reactor had been reprocessed and several tens of kilograms of plutonium removed. The nature of the discrepancy is shown schematically in **Figure 6-5**, which shows a suspect path employing the 5-MW(e) graphite reactor.

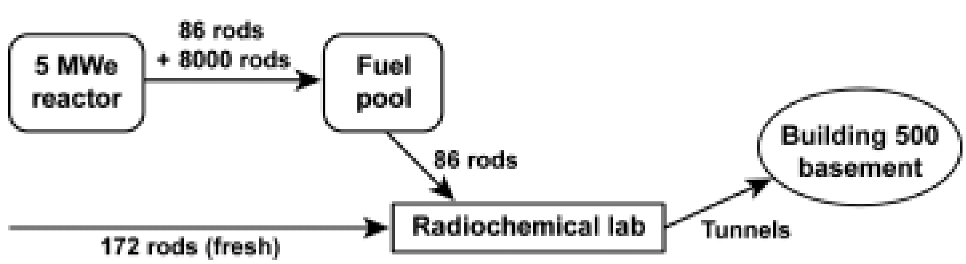


Figure 6-5. Nuclear program at 5-MW(e) graphite reactor and radiochemical lab. Declared quantities are shown as numerical values. It is suspected that as much as one additional core was processed without declaration and the wastes could be stored in Building 500, an undeclared waste site.

From satellite imagery of the steam emitted from the reactor cooling tower, a rough power history of the reactor was determined. The design of the reactor does not require the reactor to be shut down in order to remove some of the fuel. However, it was determined that significant outages had occurred during operation, which would allow large fractions of the core inventory to be removed, depending on the speed of the refueling machines available to the North Koreans. It has been estimated that during a 70-day outage in 1989, half the core could have been removed with a single refueling machine, or the entire core could have been removed with two refueling machines. Based on these rough estimates, it is likely that up to 50 tons of fuel was processed in the radiochemical laboratory, which then may have produced as much as 8.5 kilograms of plutonium. If this were the case, there would be tens of kilocuries of radioactive fission products, and tens of tons of uranium sludge in the basement of Building 500.

The North Koreans declared that the reactor operated with only one core load of fuel from 1986 until 1994, when the entire core inventory was removed and put in the spent-fuel storage pool. Currently, about 8,000 rods are sealed in cans in the fuel pool, representing this one full core load. Only about a 100 rods were otherwise removed from the core because they had failed during reactor operation. Of those rods, they were able to take 86 of them from the spent-fuel storage pool and transfer them to the radiochemical lab for "hot tests" of the facility. The other rods, they claimed, were too badly damaged to be removed from the pool and are still in the sludge in the bottom of the pool. For “cold tests” of the radiochemical lab, they claim to have used 172 fresh fuel rods. The “radiochemical lab” (reprocessing facility) was therefore declared to have only processed 86 irradiated rods and 172 fresh fuel rods. It was claimed that the processing occurred in a single campaign, consisting of three batches, in 1990.[9] The total amount of plutonium declared was a single puck of 62 grams that was shown to the IAEA.

As was mentioned in Table 6-1, the IAEA inspectors visiting the radiochemical lab in July of 1992 took a variety of samples, including swipe samples in the plutonium area of the lab. Some of the information from those measurements is shown in **Figure 6-6**. In this figure, the PUREX process is broken down into its four stages. The in-process waste in the tanks in each of the stages was analyzed for the plutonium isotopic content. The fraction of the plutonium that was ^{240}Pu was different in the tank inventory than in the plutonium metal sample shown the IAEA, which could indicate the wastes that were in the tanks were not the wastes resulting from the manufacture of the plutonium sample shown (although this measurement result in itself is not a “smoking gun” because there may have been very different extraction efficiencies in the three batches).

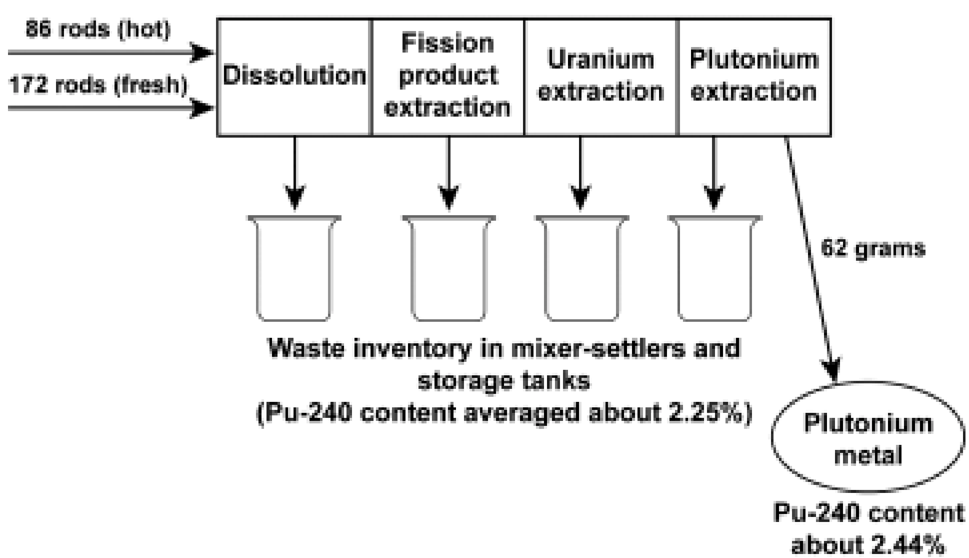


Figure 6-6. The measurements at the radiochemical lab, shown broken down into the four stages of the PUREX process. The declared input and output processing quantities are shown.

Swipe samples taken in the plutonium area of the facility provided more evidence of undeclared reprocessing campaigns. Using sophisticated techniques, the fractional content of ^{240}Pu was determined for individual dust particles. This fraction was found to vary from particle to particle, clustered in three groups, whereas the plutonium metal sample shown the inspectors was uniform. This is a very unlikely result, unless there were undeclared processing campaigns. Additionally, the ratio of ^{241}Am to ^{241}Pu was measured for these dust particles. ^{241}Pu has a fourteen-year half-life, and decays to ^{241}Am. The ratio ^{241}Am / ^{241}Pu should therefore indicate the amount of time elapsed since the plutonium was separated, as long as the initial separation was clean and the sampling and analysis were performed without the introduction of bias. This measurement indicated that reprocessing had occurred in three separate campaigns, in 1989, 1990, and 1991.

Because of the hidden waste site that is apparently associated with the IRT reactor, there is also an issue associated with that reactor. The means by which the reactor could have been used to produce plutonium is described schematically in **Figure 6-7.** The reactor used enriched uranium oxide fuel, not of sufficient enrichment for use in weapons. The fresh fuel was supplied by the Soviet Union, and spent fuel was stored in a storage canal near the reactor. It is suspected that targets that were made of natural uranium were irradiated in the neutron flux in the core of the reactor, and then transferred to the "Isotope Production Laboratory" or other facility near the IRT for plutonium removal. The total amount of plutonium that could be made by this route is probably less than four kilograms.[10]

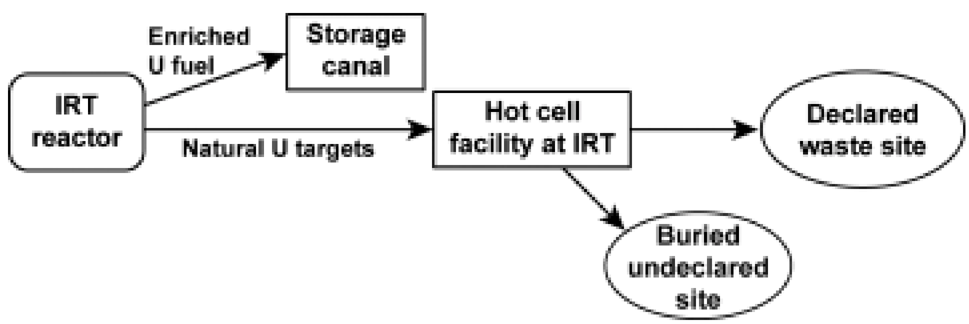


Figure 6-7. The suspected route used to produce plutonium with the IRT-2000 research reactor.

It is not clear that the building identified to the IAEA inspectors as the Isotope Production Laboratory is the facility that would have been used for this process. The North Koreans may plausibly have had a pilot reprocessing plant somewhere that enabled them to scale up to the large scale used in the Radiochemical Lab. They have denied there was a pilot facility and none has been found.

The path forward for the IAEA to determine the correctness and completeness of the initial declaration has been developed, including planning for contingencies.[11] This plan, which is not public information, will be presented to the IAEA Board of Governors sometime in the future. It includes plans for the cases where large amounts of radioactive wastes are discovered in previously hidden waste sites. There is no plan to attempt to verify the accuracy and completeness of the initial declaration unless access to the two suspect waste sites is granted, if the agency stays with the recommendations of former Director-General Hans Blix.

The roughly one core load of spent fuel remains in the pool near the 5-MW(e) graphite reactor. To prevent corrosion, the fuel has been placed in an argon atmosphere within stainless-steel cans manufactured by NAC Corporation. The cans are kept underwater for cooling. The information as to where each fuel rod was located within the reactor was lost when the DPRK refused to permit IAEA inspectors to be present and to sample materials from the rods from each of a number of key locations in the reactor when the DPRK removed the rods. Allowing such sampling could have allowed a more accurate reconstruction of how much plutonium was produced and when.

It will be important to perform measurements on the fuel along with isotopic depletion calculations to determine the reactor operation history. Typically, a set of fuel rods is put into a machine sensitive to emitted neutrons. Spontaneously emitted, neutron-rate measurements can determine the relative ^{240}Pu content of the fuel. A neutron source is then placed adjacent to the fuel rod, and the measurement of stimulated neutron emission rate can determine the relative fissile isotope (^{239}Pu and ^{241}Pu) content. From the neutron emission rates, the fuel burnup and plutonium production can be estimated. Because the rods are stored in cans now, and there could be considerable handling and radiation exposure risk in removing the rods from the cans, the cans may be measured as units. Because positional information has been lost, the uncertainty in any reactor history reconstruction will be greater than otherwise.

It will be difficult to infer accurately the reactor operational history with this information alone, so that further analysis or data may be required. It would be helpful to have the reactor operator's log books for the years when the reactor operated. Perhaps more information could be obtained by gamma-ray spectral analysis of the fuel or of structural materials within the empty reactor.

It is difficult to predict what will be found in the two suspect waste sites, if access for measurements is granted. If either of these sites is found to contain significant amounts of fission products or uranium sludge, there will be a need for the North Koreans to amend their initial declaration. If this happens, they would have to reveal the appropriate amount of separated plutonium, which may be as much as 10 kilograms. An additional facility (for plutonium storage) would then have to declared to the IAEA.

6.4 Verification of Disposal and Dismantlement

The spent fuel at the 5-MW(e) graphite reactor is to be disposed of simultaneously with the installation of the nuclear components and final construction of the first LWR, after a bilateral nuclear cooperative agreement is signed between the U.S. and the DPRK.

The spent fuel canisters are manufactured by NAC Corporation of Atlanta and are constructed of stainless steel, filled with inert gas, and equipped with a pressure relief valve. They were designed so as to fit within a shielded shipping cask, also manufactured by NAC Corporation.

Not too much is known about the plans for disposing of the fuel, and no agreement has been worked out between the DPRK and the U.S. on exactly how the canisters will be shipped. It is known that the U.S. Government paid the cost of the canisters to begin with, which indicates that the shipping will probably also be paid for by the U.S. It is most likely that trucks will be used to carry the canisters to a port, where they will be loaded on to a barge or a ship.

The destination for the fuel is unknown as of now, but the best place to send the fuel for technical reasons would be the Sellafield plant in the U.K., where MAGNOX fuel is routinely reprocessed. Public objection in the U.K. to this route may make this impossible. Other locations that could in theory accept the fuel are La Hague in France; Tokai or Rokkasho Mura in Japan; Idaho National Engineering and Environmental Laboratory in Idaho Falls, Idaho; and the Savannah River Site in Aiken, South Carolina. None of these sites has facilities specifically for handling MAGNOX fuel. A lesson from several cases of such opposition in the U.S., however, is that a state may be willing to consider limited and well-defined shipments of spent nuclear fuel of overriding national security interest.

After the first LWR has been completed, the DPRK will be required to dismantle its frozen nuclear facilities. If this part of the AF actually takes place, the DPRK will have already come into compliance with its INFCIRC 153 IAEA requirements and will have allowed all of its spent fuel to be removed from Yongbyon. The IAEA has compiled considerable information regarding decommissioning, which should help the DPRK in the dismantling effort. There are three stages of decommissioning as far as the IAEA is concerned:

Stage 1 (safe storage). The first contamination barrier is kept as it was during operation, but the mechanical opening systems are permanently blocked and sealed (valves and plugs, etc.). The containment building is kept in a state appropriate to the remaining hazard and the atmosphere inside the building is subject to appropriate control. Access to the building is allowed, subject to monitoring and surveillance procedures.

Stage 2 (entombment). The first contamination barrier is reduced to a minimum size and all parts easily dismantled are removed. The sealing of that barrier is reinforced by physical means and the biological shield in a reactor is extended if necessary so that it completely surrounds the barrier. After decontamination to acceptable levels, the containment building and the nuclear ventilation system may be modified or removed if they are no longer required for radiological safety. Depending on the extent to which other equipment is removed or decontaminated, access to the former containment building, if left standing, can be permitted. Surveillance around the barrier can be relaxed, but spot checks can be continued as appropriate.

Stage 3 (dismantlement). All materials, equipment, and parts of the plant in which activity remains significant despite decontamination are removed. In all remaining parts, contamination has been reduced to acceptable levels. The plant and site are released for unrestricted use. From the point of view of radiological protection, no further surveillance, inspections, or tests are necessary.

There are two major dismantlement challenges at Yongbyon. The first is the 5-MW(e) graphite reactor, which operated for several years and should be quite radioactive, and the second is the Radiochemical Laboratory (reprocessing facility), which is contaminated with fission products, uranium, plutonium, and americium. Fortunately, there is some international experience with similar facilities.

The owner of the British MAGNOX reactors, Chapelcross and Calder Hall, have submitted a detailed decommissioning strategy for those reactors. Each facility has four 60-MW(e) reactors that have operated for decades and are therefore extremely radioactive compared to the Yongbyon reactor, which is said to be of a similar design. The planned strategy assumes three stages, corresponding to the stages described above. The first stage will take 3 years, the second stage will take a subsequent 10 years. In this state, there is a dormancy period of 60 years for Calder Hall and 90 years for Chapelcross. Some more work will be required to reach the third stage at that time. The total cost is estimated at $1.5 billion for all eight reactors, and the labor requirement is 5,128 man-years.

The Yongbyon reactor is similar to these reactors but only one twelfth the size, and it is less radioactive because it has not run for as many years. It, therefore, could be estimated that the reactor will require only one third the labor needed for any of the British reactors, or about 250 man-years of labor for all three stages of decommissioning. However, it is to be remembered that the North Koreans have no experience with nuclear decommissioning and have little knowledge of the state-of-the-art.

The Yongbyon reactor should easily be brought to a Stage 1 (safe storage) state within a three-year period. Because of the special security issues surrounding this reactor, some critical pipes and possibly the reactor vessel itself could be cut with a saw to provide assurance that the Stage 1 decommissioning will not be reversed. The refueling machines and control rod drives should be removed and destroyed. Stage 2 decommissioning could begin as soon as Stage 1 is complete.

Experience obtained at the Eurochemic Reprocessing Plant in Belgium should provide some assistance for dismantling the Radiochemical Lab. This facility was constructed in the early 1960s. It was owned by a 13-nation consortium and went into active operation in July 1966 as a demonstration plant with a 60-ton annual capacity. Between 1966 and 1974, about 180 tons of LEU fuel were reprocessed. After being shut down in January 1975, the plant was decontaminated from 1975-79 for keeping it in a safe standby condition at a reasonable cost.

Among the buildings identified in 1987 for dismantling during a first phase are the reprocessing plant itself, the analytical laboratory, the storage facility for end-products, and the storage tanks for high- and intermediate-level liquid waste. This first phase is estimated to cost a total of $172 million and require 835 man-years of labor. The decontamination standards used in that estimate were probably much more stringent than would be expected to be used in North Korea. It is estimated that about 272 tons of waste will require geological disposal and 4,200 tons will require shallow land burial. About 54,000 cubic meters of low-level liquid waste will be generated.

Again, it may be sensible to cut some of the crucial pipes and remove some of the special equipment and destroy it early in the process because of the desire to make the dismantlement irreversible.

6.5 What Could Be Done With INFCIRC 540?

If the DPRK accepted the new safeguards protocol (INFCIRC 540) under consideration by other countries including South Korea, as discussed in Chapter 2, there would be two significant changes.

First, the IAEA inspectors could ask as a matter of right to inspect undeclared locations. Under the existing INFCIRC 153 safeguards, the practice of the IAEA is to require inspectors to request the IAEA Board of Governors to approve a “special inspection” for undeclared facilities before going beyond declared facilities. If the Board approves, the inspector then has a legal right to inspect the area requested. This is what happened in 1992 when the DPRK refused the inspection and withdrew temporarily from the NPT.

Even under the new INFCIRC 540 protocol, the inspector cannot force an inspection upon an unwilling country. The inspector can only demand one, and if refused, report what has happened to his superiors at the IAEA in Vienna. Given the DPRK history, the inspector is likely to call the IAEA before demanding an inspection outside of declared areas, unless Vienna has already told the inspector what to ask for.

A second major advantage of the new protocol is that environmental samples can be taken at places other than within declared sites. If the DPRK permitted that to be done, the sampling might produce useful evidence, as discussed in detail in Section 4.6. However, the DPRK has so far refused to agree to the new protocol. On the other hand, if the DPRK cooperates as South Africa did, it might well permit environmental monitoring outside the declared areas even though it had not agreed to the new protocol.

Chapter 6 Notes

[not called out] National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium*, Report of the Committee on International Security and Arms Control (Washington, D.C., National Academy Press, 1994), p. 151.

2. Albright, Chapter 3, p. 9.

3. Albright, Chapter 8, p. 4.

4. G. Kaurov, "A Technical History of Soviet-North Korean Nuclear Relations," in J.C. Moltz and A.Y. Mansourov, eds, *The North Korean Nuclear Program: Security, Strategy and New Perspectives from Russia*, Routledge Press, 2000, pp. 17-18.

5. The PUREX process, or Plutonium Uranium Reductive Extraction, is used ubiquitously to reprocess spent fuel. See Benedict, Pigford, and Levi, *Nuclear Chemical Engineering*, McGraw-Hill Book Company, New York, 1981.

6. Albright, Chapter 8, p. 11.

7. Albright, Chapter 8, p. 14.

8. Albright, Appendix 4.

9. Albright, Chapter 4, p. 9.

10. Albright, Chapter 6, p. 14.

11. Ollie Heinonen, IAEA, personal communication, October 16, 2000.

CHAPTER 7
Timeline for Verification and Safeguards

In this chapter, we present a simplified timeline that focuses on the verification and safeguards issues. The material relevant to the AF timeline from earlier chapters is brought together and the implications for verification and safeguards of each step in the timeline are noted. Based on this timeline, Chapter 7 presents an analysis of what can go right and wrong with the AF from the standpoint of verification and safeguards.

Seven major time-linked steps in the AF and related agreements may be identified, of which all but the first require verification or safeguards:

1. Completion of a significant portion of the project site at Kumho, DPRK, and of the first KEDO reactor in the ROK.
2. IAEA declaration that the DPRK is in compliance with its safeguards agreement.
3. Start of delivery of key nuclear components of the first KEDO reactor to the Kumho project site simultaneously with start of transfer of DPRK spent fuel from Yongbyon to its ultimate disposition.
4. Completion of Yongbyon spent fuel transfer and of the first KEDO reactor simultaneously.
5. Dismantlement of DPRK graphite-moderated reactors and related facilities at Yongbyon begins.
6. Deliveries of the nuclear components for the second KEDO reactor in parallel with proportional steps by the DPRK to dismantle all its graphite reactors.
7. Completion of second KEDO reactor at Kumho.

In addition, there is another step not explicitly linked into the timeline but which must be carried out if verification that the DPRK does not have nuclear weapons-usable material is to be complete:

8. Transfer of KEDO spent fuel when appropriate out of the DPRK.

We review briefly what information is to be expected from each step, how long each step will take, and what must take place before the step can be taken.

7.1 Completion of a Significant Portion of the Project Site at Kumho, DPRK, and of the First KEDO Reactor in the ROK

Before the DPRK is obligated by the AF to permit IAEA inspections beyond its declared facilities, a “significant portion of the LWR project” at the Kumho site must be completed. The steps to be completed have been spelled out in Chapter 1. They include:

- Completion by KEDO of site preparation, excavation, and major building construction at Kumho.
- Completion of the nuclear plant design for the LWRs by ROK.
- Delivery of the turbine generators for the first LWR, with other delivery details still to be agreed on.

As noted earlier, it would be advantageous to South Korea, the major nuclear reactor supplier and provider of money, for the IAEA and DPRK to begin negotiations soon on the special expanded inspections and to get them started before too much is invested in site preparation, construction, and manufacturing. But, there is no DPRK obligation to permit these IAEA inspections prior to those investments, and the DPRK has not so far volunteered to cooperate on this matter. If it does not, the inspections of undeclared facilities cannot begin for 2-3 years at least, more if the current problems holding up delivery of the turbine generators are not resolved in that time.

7.2 IAEA Declaration that the DPRK is in Compliance with Its Safeguards Agreement

After the step above, the DPRK is obligated to come into full compliance with its safeguards agreement, including taking all measures that may be deemed necessary by the IAEA "to verify the accuracy and completeness of the DPRK's initial report [to the IAEA] on all nuclear materials in the DPRK." These measures, and the information they will yield, include:

- Visual inspections of all declared and undeclared suspect facilities at Yongbyon as detailed in Chapter 6, including the possible undeclared waste sites, to identify facilities used for plutonium production and separation, waste storage, radiochemistry, and any other potential nuclear weapon-related activity.
- Measurements, including swipe and particle assays, of all equipment, surfaces, and other material at these facilities that could contain or have contained any product associated with the production and storage of plutonium.
- Analysis of at least some of the spent fuel from the reactor at Yongbyon, and of any waste or other relevant material recovered.
- Identification and visits to sites, other than those at Yongbyon, suspected of being used for nuclear materials-related activities. If identified, measurements similar to those at Yongbyon would have to be made. Identification of sites outside of Yongbyon may require some use of national technical means of surveillance as well as cooperation from the DPRK.

These measures should yield an estimate of the amount of nuclear-weapon material made and of the forms it may be stored in, together with an estimate of the capability of the DPRK to make more such material. They could also yield information regarding what other parts of a nuclear-weapon program the DPRK has carried out. They could lead to a need to modify the original DPRK declaration, which, in turn, could jeopardize the AF.

Verification of accuracy and completeness of the DPRK declaration is needed for the IAEA to declare the DPRK to be in compliance. The time needed to complete this verification is difficult to estimate. The Director General of the IAEA has told both the IAEA General Conference and the UN General Assembly that he believes it will take 3-4 years for the IAEA to complete this task, presumably assuming DPRK cooperation.

If insufficient cooperation is forthcoming, attempts to complete this step could bring about an indefinite delay. Furthermore, if the DPRK declaration and the IAEA findings cannot be brought into agreement, the AF could end. We discuss the implications of those two outcomes in Chapter 8.

The AF is silent on what should be done if spent fuel, waste, or separated plutonium is found outside the ponds where the declared spent fuel is stored at Yongbyon. As noted in Chapter 6, however, there is no plan to attempt to verify the accuracy and completeness of the initial declaration unless access to the two suspect waste sites is granted, if the agency stays with the recommendations of former Director-General Hans Blix. Thus, the outcome of this key step is both crucial and indeterminate. Whatever the outcome, at this point, no nuclear fuel or key nuclear component would have been delivered to the KEDO reactor site.

7.3 Start of Delivery of Key Nuclear Components of the First KEDO Reactor to the Kumho Site Simultaneously with Start of Transfer of DPRK's Spent Fuel from Yongbyon to Its Ultimate Disposition

After the DPRK comes into compliance, and simultaneously with the start of delivery of key nuclear components to the first KEDO reactor, the DPRK is obligated to begin transfer of spent fuel from the cans in the small graphite reactor pools to "its ultimate disposition," outside the DPRK if that is what KEDO wants. The spent fuel is to be completely transferred by the time the first KEDO reactor is completed.

If identification of the material to be transferred is complete and reliable, verification of this step is straightforward so long as the ultimate disposition site is outside the DPRK and under IAEA jurisdiction and control. If the material were to remain in the DPRK, continuing verification and accountability would be required.

The time needed to ship spent fuel and any separated plutonium identified out of the DPRK is probably measured in months once all preparations, both operational and diplomatic, have been made. Those preparations, however, could take much longer. Shipping appropriate to the transport of spent fuel must be made available. Possible sites for disposal are discussed in Chapter 6, Section 4.

7.4 Completion of Yongbyon's Spent Fuel Transfer and of the First KEDO Reactor Simultaneously

Upon completion of the spent-fuel transfer from Yongbyon, the first KEDO reactor can be completed. All safeguards for that reactor, discussed in detail in Chapter 4, must be installed and operational before operations can begin. Until operations begin, there will be no nuclear weapon-usable material in the reactor. About two years of prior training in maintaining the safeguards and in material accountancy are needed before the reactor can begin operation. The time needed after the completion of the first two steps noted above, and after the training has taken place, has been estimated at about a year, depending on the detailed circumstances. Delays could be incurred owing to technical and legal problems associated with the reactor itself and its safeguards, or to problems external to the reactor installation, such as the lack of an adequate electrical grid to offtake the power. These problems were mentioned previously.

The information to be expected from this step will continue to flow as the reactor operates. As noted in Chapter 4, Section 5, the global record to date suggests that no fuel diversion from a commercially operated LWR has taken place. It seems to us highly unlikely that such a breakout could be carried out undetected if the safeguards described are adequately implemented. As noted at the end of Chapter 4, Section 5, the additional measures and inspections described in that section could be useful in further lowering the probability that covert diversion could take place from a safeguarded reactor. Further, as noted in Chapter 4, Section 6, satellite monitoring, which is not a part of IAEA safeguards, could, in case of there being some intent to abrogate, give information as to the time of the breakout and the amount and form of the material involved.

7.5 Dismantlement of DPRK's Graphite-Moderated Reactors and Related Facilities Begins

7.6 Deliveries of the Nuclear Components for the Second KEDO Reactor in Parallel with Proportional Steps by the DPRK To Dismantle All Its Graphite Reactors

The timing of these parallel procedures is complex and may be contentious. Only some of the agreements between KEDO and the DPRK have been made public. Among possible points of contention particularly relevant to verification are:

- The precise meaning of "dismantlement" and of "ultimate disposition" of the dismantled parts. Chapter 6, Section 4 outlines some technical possibilities, but they are suggestions only.
- The nature and extent of "related facilities" at Yongbyon and possibly elsewhere.
- The possibilities that nuclear facilities not covered by the AF but implicitly covered by the 1992 ROK-DPRK joint denuclearization declaration, to which the two parties recently recommitted themselves, exist.
- The question of who pays for the dismantling.

Auxiliary agreements and protocols covering those points are needed. Absent knowledge of these agreements and protocols, estimates of time and verification beyond the ones made in Chapter 6, Section 4, which are based on analogy with plans for dismantling similar but larger facilities, cannot be made. According to those estimates, dismantlement would take several years owing to the radioactivity in some of the buildings, but irreversible changes could be brought about sooner.

7.7 Completion of Second KEDO Reactor at Kumho

The same verification and safeguards comments can be made here as were made in connection with the completion of the first KEDO reactor.

7.8 Shipping Spent KEDO Reactor Fuel When Appropriate out of the DPRK

According to the Supply Agreement (Art. VIII, par. 3): "KEDO and the DPRK shall cooperate to ensure the safe storage and disposition of the spent fuel from the LWR plants. If requested by KEDO, the DPRK shall relinquish any ownership rights over the LWR spent fuel and agree to the transfer of the spent fuel out of its territory as soon as technically possible after the fuel is discharged, through appropriate commercial contracts."

The spent fuel from the LWR reactors to be provided by KEDO is to be high-burnup fuel not nearly as suitable for weapons use as the fuel from the Yongbyon reactors would have been, but nevertheless a potential proliferation risk. Such fuel is left in cooling ponds at the reactor site for a period of years. After the radioactivity in the fuel assemblies has decayed sufficiently to permit handling the assemblies on dry land, the assemblies can be placed in casks and kept in dry storage for an indefinite period of time. Such dry storage is in use in the U.S. for example, but so far it has not been practiced in Asia. The assemblies continue to become less and less radioactive over the years and must continue to be monitored and accounted for until ultimately disposed of.

If the plutonium-containing spent fuel from the KEDO reactors is not to be left indefinitely in the DPRK, facilities for ultimate disposal or at least long-term dry storage must be found. This problem is not unique to the DPRK's KEDO reactors, and must be solved for all Asian and other countries that use nuclear power, although the DPRK case is particularly sensitive. Discussions about disposal and long-term storage for spent nuclear fuel in Asia have been going on inconclusively for years. The existence of spent DPRK fuel may add to the incentives for resolving them.

CHAPTER 8
Potential Failure Modes of the Agreed Framework

We present five scenarios that among them bracket possible degrees of cooperation of the DPRK with safeguarding and verification efforts. These scenarios do not capture variations in other dimensions—such as financial, regulatory, diplomatic—to which they are nevertheless linked. They serve as a rough framework for evaluating potential failure modes of the AF and their implication for verification and safeguards.

8.1 Scenario 1: The DPRK Fully Cooperates with the IAEA Regarding Existing Agreements

Under this scenario, the DPRK would:

- Allow the IAEA to carry out inspections at suspect facilities soon.
- Allow measurements on Yongbyon spent fuel and provide reactor logbooks and other documentation to help reconstruct the operating history.
- Cooperate with the IAEA in issuing a modified declaration that would reconcile the discrepancies between its previous declaration and IAEA measurements (see Chapter 6) and allow verification of that declaration. While estimates of past plutonium production vary, there is strong evidence that the North Koreans separated more than their original declaration of less than 100 grams. If so, an amended declaration will be required in order for the IAEA to certify North Korea's plutonium holdings.
- Permit IAEA inspections, measurements, and environmental monitoring at all sites where nuclear activities subject to safeguards may have occurred.
- Begin early training of its personnel in nuclear material accountability.
- Participate positively in negotiations aimed at taking spent fuel out of the DPRK (the DPRK may not be the main problem in these negotiations but its early cooperation would facilitate them).

Full implementation of North Korea's safeguards agreement with the IAEA will require that North Korea be fully cooperative with the application of advanced safeguards technologies as they evolve. As discussed in Chapter 2, even without implementation of the "Additional Protocol (INFCIRC 540)," the IAEA has the right to utilize remote and unattended monitoring systems, request ad hoc and special inspections, and review the data collected by the DPRK's national system of materials control and accounting. The DPRK will be required to make accurate measurement of several key parameters, such as quantities of nuclear material received, produced, shipped, lost or otherwise removed from inventory, and quantities of material in inventory. Procedures must be implemented for identifying, reviewing, and evaluating differences in shipper/receiver measurements; taking physical inventory; evaluating accumulations of unmeasured inventory and unmeasured losses; and providing reports to the Agency in accordance with its safeguards agreement. These safeguards measures will be applied to all nuclear material subject to safeguards, including the IRT research reactor, the LWR power reactors, and their related facilities.

Evidence to date indicates that the DPRK has not implemented such rigor in its nuclear materials accounting activities in the past. Nor has it operated nuclear facilities at the scale of the KEDO reactors. Perhaps implicit in the AF and the formulation of KEDO is the provision of necessary training and technical support to North Korea to assure that the DPRK is well prepared to accept this responsibility. As we have learned from other cooperative threat reduction programs, increased transparency with respect to the peaceful use of nuclear material is key to building a sustainable nonproliferation regime.

Full DPRK cooperation with such measures as described above would relieve pressure on the time schedule and allow for earlier operation of the KEDO reactors. Reconstruction of past activities at inspected sites (declared and suspect) could be as accurate and knowledge that nuclear-weapons activities have ceased at these facilities could be as assured—as was the case for South Africa.[1] The safeguarding of the KEDO reactors would be positively affected: there would be greater assurance that inspections, measurements, materials accounting, and data transmission would be carried out as specified in the safeguards agreement.

This scenario would represent a departure from past experience. It would speed progress on the measurable requirements of the AF, mainly contained in Articles I and IV (having to do with nuclear activities and energy supplies), and would ease working toward normalization of economic and political relations, and toward peace and security, as called for in Articles II and III. The ROK, the U.S., and Japan would thereby all find it easier to reach their respective goals under the AF. Such increased DPRK cooperation would thus lessen any incipient strain among KEDO members stemming from the members' different relative priority among these goals.

8.2 Scenario 2: The DPRK Maintains Its Present Level of Cooperation

Under this scenario, further delays can be expected. In particular, verification could almost surely not be accomplished on the presently anticipated time scale in two areas:

- Reconciling the data taken and to be taken by the IAEA regarding activities at Yongbyon with the DPRK declaration of these activities. The consequence of a failure to certify the North Korean declaration will be a function of when and how this failure occurs. Given the history of interactions with the North Koreans, issues of uncertainty in the IAEA measurements may arise. There is no predetermined standard by which "acceptable" uncertainty is measured. In fact, this is often a function of specific measurement technologies employed and the openness of the inspected party to the IAEA. As with so many things in the nonproliferation regime, it is a subject of negotiation.

- Assuring that no further nuclear-weapons-related work is going on in the DPRK, and that no separated undeclared plutonium is stored anywhere. The AF does not freeze nuclear facilities or activities other than those declared facilities at Yongbyon. Although the question of plutonium production at these facilities is in the forefront of most verification efforts, providing a determination of the "completeness" of the DPRK declaration is paramount to the continued movement of the DPRK towards membership in good standing in the NPT.

As discussed in Chapter 2, though it has rarely occurred, access to "undeclared" sites or to locations suspected of containing "undeclared" nuclear material is possible under traditional IAEA safeguards (i.e., INFCIRC 153). Several provisions under North Korea's safeguard agreement (INFCIRC 403) could assist the IAEA in making a determination of "completeness" with respect to declared nuclear facilities and materials. These include:

- Provision and verification of design information,
- Notification of new facilities or modifications to existing facilities, and
- Access for routine, ad hoc, and special inspections.

In particular, "special" inspections may be requested in cases where the information provided to the IAEA is not adequate for the Agency to fulfill its responsibilities. Special inspections may be requested at "undeclared" facilities.

It was the request for a "special" inspection of two undeclared waste sites at Yongbyon that precipitated the North Koreans to withdraw from the NPT. It seems likely that the IAEA will require access to these undeclared sites in order to verify North Korea's declarations. A full understanding of the operation of the IRT research reactor (discussed in Chapter 6) and the disposition of nuclear materials associated with its operation are among steps necessary to provide confidence that North Korea has no undeclared nuclear programs. In addition, there may be other special inspections required to fully determine that North Korea has no undeclared nuclear facilities, nuclear material inventory, or activities. This would require better DPRK cooperation than has taken place, and probably cannot be done perfectly. The best that could be done would be to identify and make measurements of the type described in Chapters 4 and 6 on any facility where plutonium is thought to have been made and separated. Some of these measurements will become impossible as time goes on.

From the verification standpoint, actions that delay verification activities beyond a certain poorly defined point can be tantamount to actions that attempt to defeat verification, period. Depending on the degree and kind of DPRK cooperation or non-cooperation in regards to safeguards and verification measures, extensive delay owing to lack of DPRK cooperation could have the same practical effect on the AF as the attempts at covert diversion and hiding of nuclear material which form the next scenario.

8.3 Scenario 3: The DPRK Attempts Covertly To Divert or Hide Nuclear Material

While declared facilities at Yongbyon are verifiably frozen, overt diversion or hiding of material from the suspect but undeclared facilities at Yongbyon (and particularly from suspect undeclared facilities elsewhere in North Korea) is feasible so long as the extensive IAEA inspections and measurements discussed above have not taken place, as noted in Chapter 6. Early inspection of suspect undeclared facilities and measurements of what is found there could help identify hidden material and prevent future diversions. Without such inspections and measurements, it cannot be known whether or not nuclear material additional to the declaration remains hidden. The techniques discussed in Chapter 4, Section 6 particularly environmental monitoring at sites other than the declared sites, would go some ways toward reducing the likelihood of successful covert diversion or hiding.

Attempts by the DPRK to divert or hide nuclear material would be incompatible with the AF. Even extensive delays, as noted, could have the same effect. Delays in carrying out the inspections and measurements discussed above at Yongbyon and elsewhere could lead to increased suspicions that material was diverted from inspections and hidden. In particular, if the DPRK were to delay effective IAEA inspections while continuing on the path of warming relations between the North and South, verification problems could evoke different responses from the KEDO members with respect to continuation of the AF. If the DPRK were to refuse to allow access to facilities and information needed by the IAEA to verify declarations, it is difficult to imagine that the U.S. would continue with its part of the AF. It is less certain what position KEDO member states might take, especially in light of domestic, bilateral, and regional political pressures.

These comments pertain to material and facilities at Yongbyon and possibly elsewhere in the DPRK but not to the KEDO reactors. Covert diversion or hiding of nuclear material generated in the course of operating the KEDO reactors would be far more difficult, as discussed in Chapters 4 and 5. So long as the IAEA and its member states are successful in obtaining full enforcement of safeguards, we believe that the probability of covert diversion from the KEDO reactors is very low. The main covert diversion or hiding problem, at least in the first many years of the AF, is connected with the earlier DPRK activities at Yongbyon and possibly elsewhere.

8.4. Scenario 4: The DPRK Abrogates the Agreed Framework or Other Key Agreement

If the DPRK were to abrogate its agreements, and, for instance, expel the IAEA inspectors, it would have control over any nuclear material left at Yongbyon and other possible sites (and over spent fuel left at the KEDO reactor site if abrogation occurs after the KEDO reactor(s) have begun operation). This is, of course, an argument for removing such material from the DPRK as soon as practicable. In the case of the KEDO reactors, “as soon as practicable” means at least a few years, as we have seen, while the spent fuel cools.

We note parenthetically that the DPRK previously (in 1994) gave a 90-day notice of intent to withdraw from the NPT, which it then “suspended.” This may leave the length of notice that may be given of any future intent to withdraw ambiguous.

In the case of abrogation, the outside world would know how much potential nuclear-weapon material there is in the DPRK at least as well as it knows now, better if inspections and removal operations at Yongbyon have been carried out. It would, as now, be able to externally monitor such large-scale activities as continued reactor operations, construction of facilities, and, to some extent, identification of major activities, as discussed in Chapter 4, Section 6. It would not be possible to know accurately how much plutonium is made in reactor operations subsequent to abrogation, should those occur, nor how much is separated, or how it is being used.

It is to be remembered that no nuclear components will be delivered to the KEDO site until a bilateral nuclear cooperation agreement is signed, which will first require that the DPRK is in full compliance with its IAEA safeguards obligations. For this to occur, there must first be a dramatic change in the transparency of the regime, as stated above. The LWR reactors would begin operation only after the DPRK has verifiably given up its Yongbyon program and its store of spent fuel.

Once these factors are considered, there is still the chance that relations with the North could change again a second time. The situation could deteriorate in the future, after the Yongbyon spent fuel has been removed and the only plutonium available to the DPRK would be that in the spent fuel at the KEDO site.

If safeguards at the KEDO reactors were abrogated, for instance following a DPRK declaration of a state of emergency, foreigners such as IAEA inspectors or ROK personnel would be forced to leave the country. Remote monitoring equipment would be disconnected or removed. After such a set of events, the risk of diversion of fuel becomes a very serious concern.

Because of the highly radioactive nature of the fuel and high heat-generation rate for the first few years after discharge from the reactor core, the older fuel in the pool would be the most likely diversion target. The 59 assemblies discharged initially from the first core load, as was mentioned in Chapter 4, each weigh about 0.6 ton and contain 3 kilograms of plutonium. The burnup will be about 12-15 MWd/ton, and these assemblies would possess the best weapon-quality plutonium of any of the fuel that has cooled for a significant amount of time. In theory, the North Koreans could take those 59 assemblies and make between 10 and 20 atomic bombs of the type detonated at the Trinity test. That test, it is to be remembered, used about 6 kilograms of weapon-grade plutonium in an "implosion" configuration and generated over 10 kilotons of explosive energy. While possible in principle, the effort to turn this plutonium into a set of explosive devices would face formidable obstacles.[2]

Because the plutonium is not separated from the fission products of the spent fuel, chemical separation must be carried out with very radioactive material. Each assembly, even if it had cooled for 15 years, would be extremely radioactive, exposing an unprotected individual to a lethal dose of more than 1000 rads every hour at a distance of one meter. Each fuel assembly would probably require a ton or more of shielding in order to remove it from the spent fuel pool. A shielded, remotely operated reprocessing facility would have to be built somewhere and tested without being detected. The testing would be hard to conceal, if it used "hot" materials, because of the release of radioactive material such as ^{85}Kr into the environment, which could be detected by remote sensors operated by U.S. intelligence. Another problem for the North Koreans would be that the zirconium cladding on the fuel is extremely difficult to dissolve in a simple PUREX facility such as the one that they built at Yongbyon. The cladding must be chopped away with a heavy, remotely operated machine before fuel dissolution.

On the other hand, its experience at constructing and operating the Yongbyon facilities would help North Korea in building this hypothetical reprocessing laboratory. Rather than building a very large facility such as the one at Yongbyon, the DPRK could rely on a simpler and lower-cost facility designed to separate enough plutonium for a few weapons, with little attention paid to health or safety. The greatest problem would be the requirement to carry the main reprocessing steps with remotely operated equipment. If the facility is built ahead of time and the procedures practiced (without actually having LWR spent fuel assemblies available for realistic tests), in principle the time needed to separate the requisite amount of material might be only days or weeks if all went according to plan. In practice, however the time needed is likely to be much longer. The IAEA's Standing Advisory Group on Safeguards Implementation has estimated that the time required to convert plutonium in spent fuel into a weapon would be one to three months, compared to seven to ten days for metallic plutonium.[3]

The manufacture of a bomb from LWR plutonium faces special difficulty due to the presence of ^{240}Pu. This isotope's primary decay mode is via alpha-particle emission but it also sometimes decays by spontaneous fission. This fission produces neutrons that may cause premature initiation of a chain reaction in a bomb before the fissile material has been fully brought together or compressed. The rate of spontaneous neutron production in the plutonium would be between 1 and 2 million neutrons per second per weapon, and predetonation is therefore likely. With predetonation, a bomb is said to “fizzle,” and produces a much smaller yield than the full design yield. If the North were to use the plutonium from the LWR reactors, it is likely that the actual yield would equal the fizzle yield. But even with relatively simple designs—within the capabilities of many nations and possibly North Korea—explosive devices could be constructed so that the assured (fizzle) yield is at least a kiloton.[4]

8.5 Scenario 5: The U.S. or the ROK Is Unable or Unwilling To Meet Its Commitments under the Agreed Framework Even Though the DPRK Does

This might be the case, for instance, if a U.S. administration determines the AF is not in the U.S. interest, or if the Congress prevents completion of a nuclear cooperation agreement. New U.S. legislation will make gaining acceptance (non-objection) from Congress more difficult and will probably put off negotiation of an agreement of cooperation. Lack of an agreement would prevent installation of nuclear components of U.S. origin. Again, at that point, no nuclear fuel would have been delivered to the KEDO reactor, and, of course, no plutonium would have been made there.

A similar issue may arise regarding nuclear liability. As noted in Chapter 2, Congress has prohibited the U.S. from agreeing to indemnify a U.S. manufacturer that provides nuclear components for the DPRK reactors. General Electric has indicated that it will not provide such components without indemnification. Negotiations have not yet produced an agreement to share this liability risk.

The scenario could also be brought about if KEDO ran into financial difficulties, perhaps owing to delays. The ROK is the principal financial backer of KEDO; its contribution, in the financial and other areas, is crucial to the successful completion and safeguarding of the KEDO reactors. The ROK could also decide to revisit its level or conditions of support if political conditions change between the two Koreas.

Such a scenario could occur before or after the verification of accuracy and completeness of the DPRK declaration had been completed. If verification had not been completed, the DPRK might delay completion of that step, bringing the verification situation closer to what it was before the AF was signed, i.e., incomplete knowledge of prior DPRK activities, and an incomplete KEDO reactor. Thus, failure on the part of the U.S. to meet its commitments to the AF in a timely way could, depending on the timing, itself jeopardize verification that the DPRK does not possess nuclear materials or facilities to carry out a nuclear program. At the same time, if IAEA inspectors remained at the Yongbyon site, activities there would continue to be verifiably frozen. The key factor is continued presence and access by the IAEA inspectors, not the pace of the AF itself, although the two are clearly linked.

Chapter 8 Notes

1. National Academy of Sciences, "Management and Disposition of Excess Weapons Plutonium," report of the Committee on International Security and Arms Control (Washington, DC: National Academy Press, 1994), p. 151.

2. Albright, Chapter 3, p. 9.

3. Albright, Chapter 8, p. 4.

4. G. Kaurov, “A Technical History of Soviet-North Korean Nuclear Relations,” in J.C. Moltz and A.Y. Mansourov, eds., *The North Korean Nuclear Program: Security, Strategy and New Perspectives from Russia* (Routledge Press, 2000), pp. 17-18.

5. The PUREX process, or Plutonium Uranium Reductive Extraction, is used ubiquitously to reprocess spent fuel. See Benedict, Pigford, and Levi, *Nuclear Chemical Engineering* (McGraw-Hill Book Company, New York, 1981).

6. Albright, Chapter 8, p. 11.

7. Albright, Chapter 8, p. 14.

8. Albright, Appendix 4.

9. Albright, Chapter 4, p. 9.

10. Albright, Chapter 6, p. 14.

11. Ollie Heinonen, International Atomic Energy Agency, personal communication, October 16, 2000.